NEW

CATECHISM

OF

ELECTRICITY

A Practical Treatise,

BY

N. HAWKINS, M. E.,

Author of Hand Book of Calculations for Engineers; Maxims and Instructions for the Boiler Room; Aids to Engineers' Examinations with Questions and Answers; Etc.

RELATING TO THE DYNAMO AND MOTOR; WIRING; THE ELECTRIC RAILWAY; ELECTRIC BELL FITTING; ELECTRIC LAMPS; ELECTRIC ELEVATORS; ELECTRIC LIGHTING; ELECTRO PLATING; THE TELEGRAPH AND TELEPHONE; MEASUREMENTS; AND TABLES.

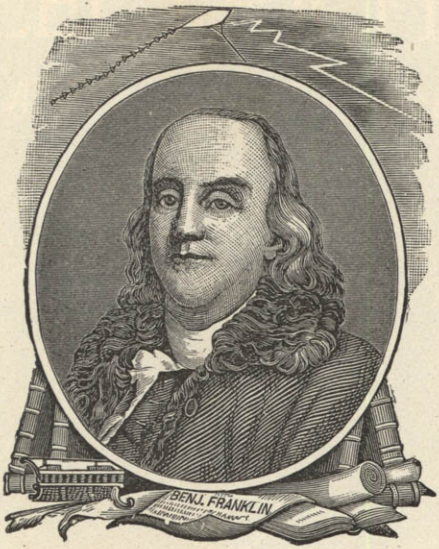
THEO. AUDEL & CO. 63 FIFTH AVE.

NEW YORK.

175

"*The vital knowledge—that by which we have grown as a nation to what we are, and which now underlies our whole existence, is a knowledge that has got itself taught in nooks and corners; while the ordained agencies for teaching have been mumbling little else but dead formulas.*"

"*That which our school courses leave almost entirely out, we thus find to be that which most nearly concerns the business of life. All our industries would cease, were it not for that information which men begin to acquire as they best may after their education is said to be finished. And were it not for this information, that has been from age to age accumulated and spread by unofficial means, these industries would never have existed.*"—Herbert Spencer.


BENJ. FRANKLIN

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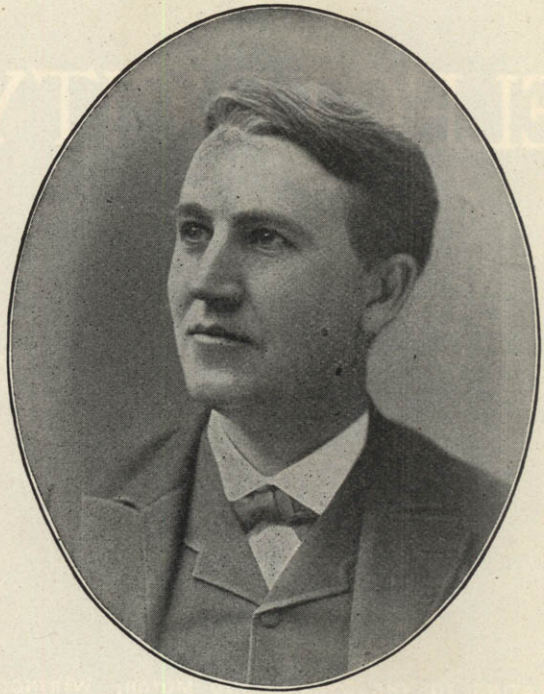


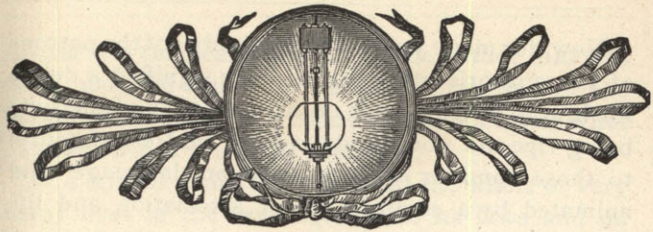
Thomas A. Edison

This work is respectfully dedicated to

THOMAS A. EDISON,

of Llewellyn Park, N. J.

"From possibilities
to realities."



PREFACE.

What can the author of this treatise say in sending it forth to be added to the much more extensive works already published relating to the same subject. He can say this.

There are a thousand spoken languages in the world, each mode of speech is more or less perfect, and easily understood.

But, outside those born to a particular tribe or nation, all other tongues, save their own, are a babel of sound—a literal gibberish.

Thus, the Chinaman cannot understand the Italian, nor the Frenchman the German, and so on through the hundreds of dialects; a man who knows six languages is rare, although Elihu Burritt, the learned blacksmith, was said to be familiar with forty or more.

It is the same with the writing of books; each author must use his own native "lingo" addressed to those born to the same tribe as himself.

Now, for many years, a large number of the patrons of the author's other books have signified a desire for him to write a work on Electricity, and the time being ripe, he now sends it forth addressed (only) to those familiar with a common language and animated by a common tie of association and life with himself.

Hence, this work is addressed; not to the experimenter or to the toy-maker, nor to the scholar in school or college, but to those who have to deal with Electricity as a part of their life work; to those who hold it in check, like a powerful horse and render serviceable this mysterious force—the rein to hold and guide it is knowledge.

Back of the desire for a considerable circulation of the printed book lies the earnest wish that it may be thoroughly useful to that class of men who must perforce use electricity as their bondsman or serve it as an inexorable master.

And this is the true office of a book relating to the arts or sciences; to explain the unvarying laws upon which all true progress is based; to classify and arrange for ready reference this information so that it may be readily available; to furnish hints and suggestions leading to further and thorough research in all lines leading from the subjects discussed; in short to reduce the every-day practice of a thousand skilled workers to an unvarying science; science being defined as the "orderly arrangement of knowledge."

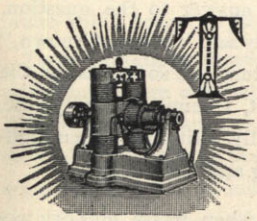
It is also the heartfelt wish of the author that this work may be found to be an introduction of the reader and student to a wide acquaintance with what may be termed electrical literature.

In a science which has occupied the whole of very many lives in the investigation of its laws and an immense expenditure of money in experimental tests, it were vain to expect from a single book much more than a limited view of some one part of the subject, or better yet, a work giving the clue to further research and study in many directions.

So, in this work the author trusts the student will at least find "the end of the rope" which drawn out will make him master of the principles and practice relating to practical Electricity. And, in the abridgement and selection of the ever-widening subject-matter, so present it, that it can at the pleasure or profit of the student, be run out to infinitude in any useful direction.

With these few introductory words and added good wishes for the progress and prosperity of the reader, the author thus apologizes (for a preface is usually an apology) for issuing a New Catechism of Electricity.

INTRODUCTION.



THE great forces of the world are invisible and impalpable; we cannot grasp or handle them; and though they are real enough they have the appearance of being very unreal. Electricity and Gravity are as subtle as they are mighty; they elude the eye and hand of the most skillful philosopher. In view of this, it is well for the average man not to try to fathom, too deeply, the science of either; neither Edison or Tesla have done that yet.

To take the machines and appliances as they are "on the market," and to acquire the skill to operate them, is the longest step toward the reason for doing it, and why the desired results follow—thus working on the natural method of judging causes from effects.

The history of the development of "Practical Electrics" does not cover many years. Not a few people can easily remember all the progressive steps from a humble beginning to the time, now, when it has become the leading study of the sceintific and engineering world.

Although electricity was known to the ancient Greeks the uses to which it might be applied have remained unknown for thousands of years. It was reserved for Franklin, Volta, Ampere, Ohm, and Farraday, with a few others, to discover the laws which govern it. The development of the science in its application to the needs of human life may be considered to date from the time of Farraday, whose career ended in 1867, after a long and brilliant career spent in scientific research.

The time has gone by when in answer to the question, "What is Electricity," it can be truly said "It is not known," for as much is now known of its nature and source as of the nature and source of Gravity, Heat, Chemical affinity, etc. The following "definitions" carefully written by men highest in authority, are both interesting and instructive.

"There are certain bodies which when warm and dry, acquire by friction, the property of attracting feathers, filaments of silk or indeed, any light body toward them. This property is called Electricity, and bodies which possess it are said to be electrified." (Linnaeus Cumming.)

"The theory of Electricity adopted throughout these lessons is, that Electricity, whatever its true nature, is one not two; that this Electricity, whatever it may prove to be, is not matter and is not energy; that it resembles both matter and energy in one respect, however, in that it cannot be created nor destroyed." (Sylvanus P. Thompson).

NOTE.—When Benjamin Franklin made his discovery of the identity of lightning and electricity, people asked: "Of what use is it?" The philosopher's retort was: "What is the use of a child? It may become a man!"

"Whatever Electricity is, it is impossible to say, but for the present it is convenient to look upon it as a kind of invisible something which pervades all bodies." (W. Perrin Maycock).

"There is nothing more certain to-day than that Electricity is not a fluid." (Prof. Rowland).

"Throughout the nineteenth century this enigma (What is electricity?) has been the object of numerous researches * * * and yet the inner working of electrical phenomena remains still a deeper mystery." (A. Stoletow.)

These quotations express all that science can give us in a time when there are published every month in the English, French and German languages over 150 issues of periodicals devoted exclusively to electrical subjects, besides which there are probably twice as many more journals devoted to other branches of science and engineering which sometimes have articles on electrical subjects.

In 1867 an English mathematician, Maxwell, proved mathematically that light and electricity were the same. In 1888 Heinrich Hertz proved by experiment that this was true, and the "pointings" of very recent investigations rather confirm the theory that they are one and the same.

NOTE.—One of the dreams of the modern scientist is the direct transformation of the radient energy of the sun into electric energy. To what extent this is possible is considered by a well-known electrical writer, who says: "It is a well-known principle in physics that in the last analysis all the forces of Nature are derived from the sun. There are the calorific and luminous vibrations of the sun, which, imprisoned in the coal strata and in combustible vegetation, afford the means of producing steam. When one reflects upon the tendency to utilize these forces in the form of electricity, a problem of first importance is to transfer the solar energy directly into electric energy without the agency of any intermediary."

Very much the same way in which electricity is concentrated by the action of the dynamo, so has the sunlight been "concentrated" by a powerful sun glass constructed in France, made under the supervision of the savant, M. de Villette. This glass generated heat sufficient to melt a copper coin of the size of our silver 25-cent piece in seven and a half seconds. George Parker, of Fleet street, London, made a glass more powerful; it was three feet in diameter and so powerful that it was actually used to melt substances which were too refractory for the furnaces. The best authorities on heat say that it had a power of 166.362 degrees Fahr. This is best understood when it is known that it only takes a temperature of 2,787 degrees to melt cast iron so that it will flow like water.

It is from those engineers and electricians who are in daily contact with electrical appliances that we are most likely to get the true definition of the subject. They say boldly and to the point, "Electricity is electricity," and motormen are frequently in the habit of describing the electric-current which drives their trolley-car, as "the juice." "Let on the juice!" or, "Shut off the juice!" this being always intelligable to the most scientific as well as the most illiterate.

The competent engineer to-day is expected to combine a practical knowledge of the engine and dynamo room with a proportionate information to be gained only by schools, books and professional instruction, intended to qualify him to operate and manage economically and intelligently, electrical machines; to install electrical plants; to perform calculations involving electrical units and to locate and remedy faults in electrical machines in general.

Not only the competent engineer, but everybody needs to acquire as much information as possible of this universal property of nature now brought into such close connection with the everyday life of modern civilization. It is the aim of this publication to so present the subject that it may be of wide and useful assistance to the student.

Quite recently a distinguished professor of Harvard University published an article in which he grouped the engineers now working side by side for the development of our material resources into three classas. First, those men, many of them eminent in the profession, who are the product of the workshop; whose experience and education have been obtained entirely in the field or workshop, and from a few available books.

Second. Men who have graduated from literary or natural science departments of colleges and have learned engineering after leaving their classes—drawn to it by a strong taste for the profession or by the pressure of circumstances.

Third, the younger men, graduated from schools avowedly technical or from the technical departments of universities. These men are gradually supplanting the other two classes, as the demand for greater attainment and better education increases, and as competition and the invention of labor-saving machinery *turns the mechanic into a laborer*, and raises the status of the educated engineer.

The next generation, the professor believes, will see the men with only workshop or academic training practically cut off from the profession of engineering.

Happily for the class for whom this work is compiled there is another side to the argument which might show that the men most handicapped in the race for supremacy is the graduate alluded to in class three, for to quote the same kindly author, only, "Occasionally our schools develop a man whose talent and capacity for work will enable him to study and to retain the higher branches of mathematics and physics, and at the same time to grasp their practical application to the need of modern life."

This practically in the end leaves the field for the self-taught, resolute workers, who with one hand execute and the other gather in and assimilate from all sources the scientific or classified knowledge necessary for the best results, economical, executive and lasting.

"Electricity has shown itself capable of infinite service, and its field is daily widening. It can bear thought on its rhythmic wings around the globe; carry the human voice hundreds of miles; deliver messages on board moving trains; flash into dazzling splendors along city thoroughfares; light the abyss of the ocean; operate countless automatic devices; warm us when cold; fan us when heated, and treasure up and repeat all sounds and harmonies. At the summons of inventive genius it has outwrought the dreams of magic."

ELECTRICITY.

While the nature and source of electricity still remains a mystery, and a constant challenge to the philosopher and engineer, many things about it have become positively known—thus—it is positively assured that electricity never manifests itself except when there is some mechanical disturbance in ordinary matter, and every exhibition of electricity in any of its multitudinous ways may always be traced back to a mass of matter.

Electricity, it is also conceded, is without weight, and, while electricity is without doubt, one and the same, it is for convenience sometimes classified according to its motion, as

1. **Static Electricity,** or electricity *at rest.*
2. **Current Electricity,** or electricity *in motion.*
3. **Magnetism,** or electricity *in rotation.*
4. **Electricity in vibration** (Radiation).

NOTE.—ELECTRICITY is a name derived from the Greek word ELECTRON—amber. It was discovered more than 2,000 years ago that amber when rubbed possessed the curious property of attracting light bodies. It was discovered afterwards that this property could be produced in jet by friction, and in A. D. 1600 or thereabouts, that glass, sealing-wax, etc., were also affected by rubbing, producing electricity.

Other useful divisions are into

1. **Positive** and

2. **Negative Electricity.**

And into

1. **Static,** as the opposite of

2. **Dynamic Electricity.**

There are still other definitions or divisions which are in every-day use, such as "Frictional electricity," "Atmospheric electricity," "resinous electricity," "vitreous electricity," "photo-electricity," etc., etc.

While it is almost certain that, broadly, magnetism and electricity are one, in practice it is a necessity to use these divisions to explain the various conditions and uses to which they are put and in which they exist.

USEFUL DEFINITIONS RELATING TO ELECTRICITY.

Static Electricity. This is a term employed to define electricity produced by friction. It is properly employed in the sense of a static charge which shows itself by the attraction or repulsion between charged bodies. When static electricity is discharged, it causes more or less of a current, which shows itself by the passage of sparks or a brush discharge; by a peculiar prickling sensation; by a peculiar smell due to its chemical effects; by heating the air or other substances in its path; and sometimes in other ways.

NOTE.—Statics is that branch of mechanics which treats of the forces that keep bodies at rest or in equilibrium. *Dyuamics* treats of bodies in motion. Hence static-electricity is electricity at rest. The earth's great store of electricity is at rest or in equilibrium.

That branch of the science which treats of the laws of electricity residing on the surface of bodies, as a charge, is termed *electro-statics.*

Current electricity. This may be defined as the quantity of electricity which passes through a conductor in a given time—or, electricity in the act of being discharged, or electricity in motion.

An electric current manifests itself by heating the wire or conductor, by causing a magnetic field around the conductor and by causing chemical changes in a liquid through which it may pass.

Radiated electricity is electricity in vibration. Where the current oscillates or vibrates back and forth with extreme rapidity, it takes the form of waves which are similar to waves of light.

Positive electricity. This term expresses the condition of the point of an electrified body having the higher energy from which it flows to a lower level. The sign which denotes this phase of electric excitement is +; all electricity is either positive or, —, negative.

Negative electricity. This is the reverse condition to the above and is expressed by the sign or symbol —. These two terms are used in the same sense as *hot* and *cold*.

In 1749, Benjamin Franklin observing lightning to possess almost all the properties observable in electric sparks, suggested that the electric action of points, which was discovered by him, might be tried on thunder-clouds, and so draw from them a charge of electricity. He proposed, therefore, to fix a pointed iron rod to a high tower, but shortly after succeeded in another way. He sent up a kite during the passing of a storm, and found the wetted string to conduct electricity to the earth, and to yield abundance of sparks. These he drew from a key tied to the string, a silk ribbon being interposed between his hand and the key for safety. Leyden jars could be charged, and all other electrical effects produced, by the sparks furnished from the clouds. The proof of the identity was complete. The kite experiment was repeated by Romas, who drew from a metallic string sparks 9 feet long. In 1753, Richmann, of St. Petersburg, who was experimenting with a similar apparatus, was struck by a sudden discharge and killed.

Atmospheric electricity is the free electricity of the air which is almost always present in the atmosphere. Its exact cause is unknown.

The phenomena of atmospheric electricity are of two kinds; there are the well-known manifestations of thunderstorms; and there are the phenomena of continual slight electrification in the air, best observed when the weather is fine; the Aurora constitute a third branch of the subject.

Dynamic electricity. This term is used to define current electricity to distinguish it from static electricity. This is the electricity produced by the Dynamo.

Frictional electricity is that produced by the friction of one substance against another.

Resinous electricity. This is a term formerly used, in place of negative electricity. The phrase originated in the well known fact that a certain (negative) kind of electricity was produced by rubbing rosin.

Vitreous electricity is a term, formerly used, to describe that kind of electricity (positive) produced by rubbing glass.

Magneto-electricity is electricity in the form of currents flowing along wires; it is electricity derived from the motion of magnets—hence the name.

Voltaic electricity. This is electricity produced by the action of the voltaic cell or battery.

Electricity itself is the same thing, or phase of energy by whatever source it is produced and the foregoing definitions are only given as a matter of convenience to aid in its daily application to the service of man.

Early Experiments in Electricity.

"A shock was in this manner sent through a regiment of soldiers. At an early period in the progress of electrical discovery, M. Nollet transmitted a discharge through a series of 180 men; and at the convent of Carthusians a chain of men being formed extending to the length of 5,400 feet, by means of metalic wires extended between every two persons composing it, the whole series of persons was affected by the shock at the same instant.

Experiments on the transmission of the shock were made in London by Dr. Watson, in the presence of the Council of the Royal Society, when a circuit was formed by a wire carried from one side of the Thames to the other over Westminster Bridge.

One extremity of this wire communicated with the interior of a charged jar, the other was held by a person on the opposite bank of the river. This person held in his other hand an iron rod, which he dipped in the river. On the other side near the jar stood another person, holding in one hand a wire communicating with the exterier coating of the jar, and in the other hand an iron rod, This rod he dipped in the river when instantly the shock was received by both persons, the electric fluid having passed over the bridge, through the body of the person on the other side, through the water across the river, through the rod heid by the other person, and through his body to the exterior coating of the jar.

Familiar as such a fact may now appear, it is impossible to convey an adequate idea of the amazement bordering on incredulity with which it was at that time witnessed."

MAGNETISM AND MAGNETS.

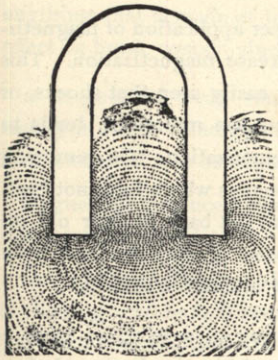


FIG. 10.

MAGNETISM is that branch of science which treats of the nature and properties of magnets and magnetic fields.

The theory proposed to account for the magnetization of iron is as follows: Each little particle of iron is supposed to be, and to remain always magnetic. In an unmagnetized iron bar these molecular magnets are arranged irregularly. These little molecules resist being turned out of their usual positions. Hence when a magnetizing force is brought to bear upon them, the first effect is to turn those little molecules round, whoses axes are already

NOTE.—The name magnet was given by the ancients to certain hard black stones found in various parts of the world, notably at Magnesia in Asia Minor, which possessed the property of attracting to them small pieces of iron or steel. This magic property, as they deemed it, made the magnet-stone famous; but it was not until the tenth or twelfth century that such stones were discovered to have the still more remarkable property of pointing north and south when hung up by a thread. This property was turned to advantage in navigation, and from that time the magnet received the name of lodestone (or "leading-stone"). The natural magnet or lodestone is an ore of iron, known to mineralogists as *magnetite*. This ore is found in quantities in Sweden, Spain, Arkansas, the Isle of Elba and other parts of the world: it frequently occurs in crystals, the usual form being the regular octahedron.

most nearly in the direction of the magnetizing field. As the magnetizing force increases others are turned, increasing thereby the apparent magnetism ; at last, all are turned with their poles in the direction of the magnetizing field.

When this is the case, no further application of magnetizing force, however great, can increase magnetization. This is the point of saturation. It is easily seen that shocks, or heating, or anything which loosens the molecules, tends to facilitate the acquirement of magnetization. On removing the magnetizing force, those molecules which have not been much strained out of their position, fall back to their old directions; but those which have been greatly strained have acquired a permanent *magnetic set*, and hence remain.

In the case of torsion or twisting of a wire, we have a similar behavior. A slight torsion within the limits of elasticity disappears when the twisting force is removed, but a violent torsion results in a permanent deformation, which does not disappear when the twisting force is removed.

This theory explains how iron can remain, as it were, super-charged or super-saturated with temporary magnetism. In the iron there is very little resistance to magnetization ; that is to say, the molecules do not resist very strongly being turned in similar magnetic directions, and hence when the force is removed, there is very little restoring tendency to make them go back into irregular positions, but a little knock or twist imparts just the necessary disturbance, and causes the regularity to dissappear, and with it the apparent magnetism.

MAGNETISM AND MAGNETS.

Magnetism is like electricity, it cannot be seen; that it exists is assured by certain effects which it produces. Toy magnets shaped like a horseshoe exhibit the principles upon which magnetism acts; *i. e.*, magnets attract and hold fast anything that is made of iron and steel, while they have no effect on brass, copper, zinc, gold or silver.

A magnetized body cannot be regarded as a source of energy in itself. Energy must be expended to magnetize the iron, and must also be expended to demagnetize it.

Magnetism produces electricity as well as electricity produces magnetism.

During the application of the magnetizing force, any blows or shaking tend to facilitate the acquirement of magnetism, but when removed from the field, the same causes tend to remove it. Heat operates in the same way. If a piece of steel is made red hot, then placed in a strong magnetic field and suddenly cooled, it acquires very strong permanent magnetism. Iron at a bright red heat is, however, not affected by a magnet. If a piece of iron, or better still, a piece of hard steel, be rubbed with a lodestone, it will be found to have also acquired the properties characteristic of the magnet; it will attract light bits of iron and steel.

This was all, or nearly all, that was known of the magnet until 1600, when Dr. Gilbert published a large number of magnetic discoveries in his famous work "*De Magnete.*" He observed that the attractive power of a magnet appears to reside at two regions, and in a long-shaped magnet these regions, or poles, are usually at the ends. The portion of the

magnet which lies between the two poles is apparently less magnetic, and does not attract iron filings so strongly; and all round the magnet, halfway between the poles, there is no attraction at all. This region Gilbert called the equator of the magnet, and the imaginary line joining the poles he termed the axis.

There is no insulator for magnetism. It penetrates everything known. The so-called protectors against magnetism are really only excellent conductors which form a short cut for the magnetism around the article to be protected.

If a sheet of glass, or wood, or paper, be interposed between a magnet and the piece of iron or steel it is attracting, it will still attract it as if nothing were interposed. A magnet sealed up in a glass tube still acts as a magnet. Lucretious found a magnet put into a brass vase attracted iron filings through the brass. Gilbert surrounded a magnet by a ring of flames, and found it still to be subject to magnetic attraction from without. Across water, vacuum, and all known substances, the magnetic forces will act; with the single exception, however, that magnetic force will not act across a screen of iron or other magnetic material. If a small magnet is suspended inside a hollow ball made of iron, no outside magnet will affect it. A hollow shell of iron will therefore act as a magnetic cage, and screen the space inside it from magnetic influences.

All magnetized substances whether permanently or temporarily magnetized have what is called *polarity*. The pole which tends to point northward when free to move is called the north pole. The other is the south pole. When two

magnets are placed near to each other the N. pole of one is found to repel the N. pole and to attract the south pole of the other; and the reverse. It is precisely by this attraction and repulsion that motive power is produced by the agency of electricity.

The magnetic field is the space around the magnet in which the compass needle or other detector of magnetism will be affected. The magnetic field is said to be comprised of lines of force. These are infinite in number, and gradually become weaker and weaker, until they disappear as the distance from the magnet is increased.

The magnetic circuit is a closed circuit. The lines of force starting from the N. pole and entering again at the S. pole.

Magnetic Flux.—This term indicates the number of lines that pass through the magnetic current. It has the same meaning as the term "magnetic flow."

Magnetic Lag.—This is the tendency of hard iron and steel to take up magnetism slowly and part with it slowly. "Magnetic retardation" has the same meaning, also "magnetic inertia."

Magnetic Saturation is the greatest magnetic force which can be permanently imparted to a steel bar.

Residual Magnetism.—When a mass of iron has once been magnetized, it becomes a difficult matter to entirely remove all traces when the magnetizing agent has been removed, and, as a general rule, a small amount of magnetism is permanently retained by the iron. The magnetism so retained by the iron is known as *residual magnetism*, and it varies in amount

with the quality of the iron. Well-annealed, pure, wrought-iron, as a rule, possesses very little residual magnetism, while, on the other hand, wrought-iron, which contains a large percentage of impurities, or which has been subjected to some hardening process, such as hammering, rolling, stamping, etc., and cast-iron possesses a very large amount of residual magnetism. This property of residual magnetism in iron is of great importance in the working of the *self-exciting* dynamo, and is, indeed, the essential principle of this class of machine.

The Magnetic Field.—It is now understood that the phenomena of magnetism are due to an atmosphere of magnetic influence which surrounds the poles, and to a lesser, the whole of the magnet. This atmosphere is termed the magnetic field.

Magnetic Tick.—When a bar of iron is suddenly magnetized or demagnetized, it emits a slight sound, called the "page sound" or the magnetic tick.

NOTE.—If the North pole of a magnet is presented to the South pole of another magnet, they will attract and hold fast to each other; but, if a South pole is presented to another South pole or a North pole to a North pole, they will repel each other, and there will be no attraction.

MAGNETISM AND MAGNETS.

Strength of a Magnet.—The "*strength*" of a magnet is not the same thing as its "lifting power." The strength of a magnet is the strength of its poles. The strength of a magnet pole must be measured by the magnetic force which it exerts.

The lifting power of a magnet depends both upon the form of the magnet and on its magnetic strength. A horse-shoe magnet will lift a load three or four times as great as a bar magnet of the same weight will lift. The lifting power is greater if the area of contact between the poles and the armature is increased. Also the lifting power of a magnet grows in a very curious and unexplained way by gradually increasing the load on its armature, day by day until it bears a load which at the outset it could not have done. *Nevertheless* if the load is so increased that the armature is torn off, the power of the magnet falls at once to its original value. The attraction between a powerful electro-magnet and its armature may amount to 200 lbs. per square inch. (See fig. 15, page 46.)

Small magnets lift a greater load in proportion to their own weight than large ones. A good steel horse-shoe magnet weighing itself one pound ought to lift twenty pounds' weight. Sir Isaac Newton is said to have possessed a little lode-stone mounted in a signet ring which would lift a piece of iron 200 times its own weight.

USEFUL DEFINITIONS RELATING TO MAGNETS.

Magnets made of steel are usually called permanent magnets; these are of two forms, viz., the "bar magnet" and the "horseshoe magnet," which is merely the bar magnet turned around.

Artificial Magnet.—Any magnet not found in nature is an artificial magnet.

Horseshoe Magnet.—This is a magnetized bar of iron or steel bent in the form of a horseshoe or letter U. (See Fig. 10.)

Natural Magnet is a name sometimes given to a lodestone. Natural magnets are usually of irregular form, although they are sometimes reduced to regular shapes by cutting and grinding.

Compound Magnets consist of a number of single magnets separately magnetized, and afterwards bound together in bundles. Compound magnets are stronger in proportion to their weight than single magnets.

Permaneut Magnet.—A magnet of hardened steel which retains its magnetism a long time after being magnetized. A permanent magnet will always attract and hold pieces of iron and steel. Its ends or poles are named North and South. There is usually a loose piece of steel or iron, called an "armature" put across the ends, which has the peculiar property of keeping the magnetism from becoming weaker.

A Polarized Electro-Magnet is one whose core is a permanent magnet. Such magnets are used in Duplex Telegraphy. The armature of this magnet is released only by a current in a fixed direction.

ELECTRO MAGNETISM.

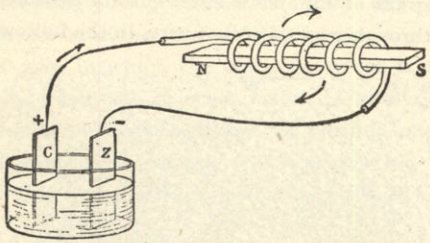


FIG. 11.

Electro-magnetism is the foundation stone of commercial electricity.

A magnet produced by passing an electric current through a wire conductor coiled around a bar of soft iron is called an electro-magnet; if the bar be of iron it will be a magnet only so long as the current flows, and electro magnetism is that science which relates to magnetism produced by the electric current, and which treats of the relation between electric currents and magnetism.

In 1820 Oerstedt made the important discovery that a conductor through which a current of electricity is passing acquires thereby all the properties of a magnet.

NOTE.—The great usefulness of the electro-magnet in its application to electric bells and telegraphic instruments lies in the fact that *its magnetism is under the control of the current;* when circuit is "made" it becomes a magnet, when circuit is "broken" it ceases to act as a magnet.

ELECTRO MAGNETISM.

Almost immediately after Oerstedt's discovery, Arago and Davy independently discovered how to magnetize iron and steel by causing currents of electricity to circulate round them in spiral coils of wire. The method is shown in the simple diagram of Fig. 11 where a current from a single cell is passed through a spiral coil of wire, in the hollow of which

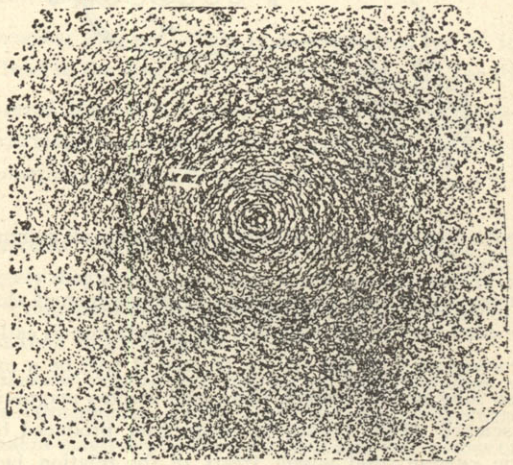


FIG. 12.

is placed a bar of iron or steel, which is thereby magnetized The separate turns of the coil must not touch one another or the central bar, otherwise the current will take the shortest road open to it and will not traverse the whole of the coils. To prevent such short-circuiting by contact the wire of the coil should be overspun with silk or cotton, or covered with a layer of gutta-percha.

ELECTRO MAGNETISM.

All dynamic-electric machines are based upon that branch of electric science known as Electro Magnetism, hence this discovery marks one of the most important epochs in the progress of practical electricity.

This exceedingly important elementary fact in electro magnetism can be shown in a variety of ways.

When a wire in which the electric current is flowing is brought near a compass or other magnetic needle, the latter will be affected and tend to change its position and set itself at right angles to the conductor. This proves that an electric current flowing in a wire is in itself a form of a N. of magnet.

Lines of Magnetic Force.—If a thin piece of paper is placed over a bar magnet and fine iron filings are sprinkled over it, the particles of iron will arrange themselves in regular curves between the poles and to map out or define lines in the magnetic fields which scientists call lines of force. See Fig. 12.

Fig. 10 exhibits the manner in which the filings arrange themselves about the ends of a horse shoe magnet.

The forms of the curves show not only the direction of the magnetic force, but they also enable us to draw conclusions as to its intensity. When the force is great the curved lines are thick and sharply defined, and when it is weak the lines are thin and less plain.

The lines of force are also to be found in the neighborhood of wires through which electric currents are passing. They are the outward effect produced by the passage of an electric current, but the most singular fact is that they can also be the cause of an electric current.

ELECTRO MAGNETISM.

Directions of Magnetic Force.—The direction of the magnetic force in a magnetic field may be defined as the direction in which a small pivoted magnetic needle points when held in the field at that point. If a small suspended magnetic needle or pocket-compass be placed at various points in the magnetic field surrounding a bar magnet, as represented in

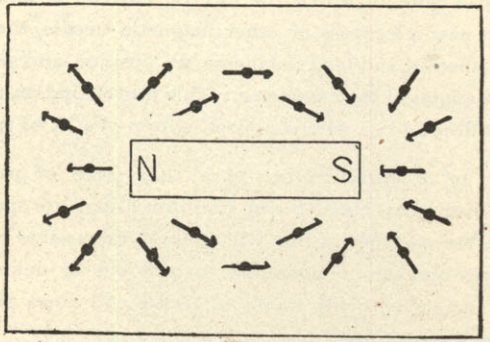


FIG. 13.

Fig. 13, it will be found that the needle always points in a definite direction, which direction varies with its position in the field, the direction of the magnetic axis of the needle at any point representing the direction of the magnetic force at that point.

If a magnetic needle, similar to that in the above experiment, be suspended by means of a thread over a bar magnet, and moved from the north to the south pole of the magnet, as illustrated in Fig. 14, the centre of the needle will trace out curving lines connecting the two poles. The paths or lines followed by the centre of the magnetic needle are

termed *lines of magnetic force*, and in the modern conception of a magnetic field this latter is assumed to be entirely filled up with these imaginary lines of force. These lines of force are assumed, for reasons to be hereafter understood, to have a certain positive direction, namely that direction in which a small north-seeking magnetic pole would tend to

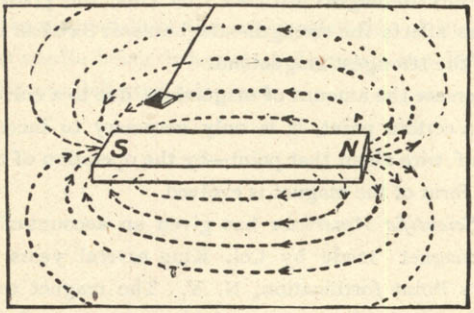


FIG. 14.

move if placed in the magnetic field; or, in other words, the lines of force are assumed to *stream* or *flow* in a direction from the north to the south pole, as indicated by the arrows in Fig. 14.

Points Relating to Electro-Magnets.

Electro-magnets are far more powerful in proportion to their size than steel magnets and can be made of any required size, those made for power stations sometimes weighing several tons.

Electro-magnets are used in nearly all electrical instruments not only because they are stronger than permanent magnets,

but because they can be made to act instantly by pasing a current of electricity through them at the most convenient moment.

The strength of an electro-magnet depends directly on the number of turns of wire and the current flowing through them.

In an electro-magnet with an iron core, the grade of the iron also affects the strength—the best soft Swedish iron furnishing the strongest magnetism.

To increase the amount of magnetism, due to a current in a wire at a certain point, it is only necessary to increase the length of wire about that point—by the operation of this law, the coil form of the magnet is evolved.

The *Scientific American* has given an account of a great electro-magnet made by Col. King several years ago at Willett's Point fortification, N. Y. The magnet core consisted of two old 15-inch guns, weighing 50,000 pounds each. It was turned into a club-footed magnet by the addition of many tons of heavy iron plates. The coil consisted of old torpedo cables 14 miles long, carrying 20 to 25 amperes. The armature consisted of 6 platform plates bolted together. A calculated force of 44,800 pounds was insufficient to tear off the armature, the chain used being broken by the strain. Five cannon balls,

NOTE.—Inasmuch as the field-magnets of dynamos are electro-magnets, the iron cores of which are excited by electric currents circulating in surrounding coils, it becomes a matter of primary importance to us to know what is the law that governs the electro-magnet. If we once know the relation that subsists between the exciting current and the magnetism that is produced by it, we can apply this knowledge to the design of dynamos; for such knowledge will enable us to calculate beforehand the size of field-magnet and the number and gauge of coils that will be required in a dynamo that is to furnish any given amount of electric energy.

of 325 pounds each, were suspended like a chain from the muzzle of the gun. An iron spike placed against the breast of a man standing three or four feet off, with his back to the gun stood out straight. It required the efforts of two men with a sudden jerk to pull away a 25-pound bar from the gun. The entire mass of iron, including guns, carriages, armature, etc., weighed over 130,000 pounds. At a distance of 71 feet the magnetism of the gun equaled that of the earth, a compass needle being deflected 45 degrees; at a distance of 300 feet it was deflected 3 degrees.

ELECTRIC ENERGY.

The production of electricity is simply a transformation of energy from one form into another, usually mechanical energy is changed into electrical energy and a dynamo is simply a device for effecting the transformation.

Prof. Fessenden truly remarks there are two independent properties of matter—gravity and inertia—and these give us two ways of defining force and energy.

It should always be remembered that electricity is something real, although not easily defined. And then, too, while it is not matter and not energy, yet under proper conditions, it having the power of doing work it is convenient to speak of its performance as electric energy. The following questions and answers, although few in number may present the subject with considerable clearness.

Ques. What is energy?

Ans. Energy is the capacity for doing work. Steam under pressure is an example, a spring bent ready to be released is another form.

Ques. What is matter?

Ans. Matter is anything occupying space, which is of three dimensions—wide, long, deep—and which prevents other matter from occupying the same space at the same time.

Ques. What is the smallest quantity of matter which can exist called?

Ans. An atom. An atom means that which cannot be cut,

scratched, or changed in form and that cannot be affected by heat or cold or any known force; although inconceivably small, atoms possess a definite size and mass.

Ques. What is a molecule?

Ans. A molecule is composed of two or more atoms.

Ques. Why at this point are definitions most useful of energy and of matter?

Ans. Because, as stated, all electric action is an exhibition of energy, and energy must act through matter as its medium.

Ques. What is the difference between electricity and magnetism?

Ans. The ultimate nature of neither is known. There are, however, some differences. To sustain a current of electricity requires energy. To sustain magnetism requires no energy.

NOTE.—A writer in the *New Science Review* undertakes to answer the question, "What is Electricity?" In order to lead the reader up to the main question, he first considers the natural forces, gravitation and heat. Examples are given of how these forces are manifested, and how energy is changed from one form to another. Every form of force, the author says, should be regarded as a different method in which energy makes itself known to the senses. He calls particular attention to the important fact that the "resistance of one kind or another is always the agent that acts to alter energy from one form to another," and suggests that electricity is simply a form or manifestation that energy may assume under given conditions, and generally is a mere transitory stage between the mechanical form and the heat form. "In most operations," he continues, "mechanical force passes to the heat form without passing through the electric form; but whenever magnetism is brought into play as a resistance that must be overcome; then mechanical power applied to overcome this resistance always becomes electricity, if only momentarily in its passage from the mechanical to the heat form." In conclusion, he asks if the question "What is Electricy?" cannot be answered in a fairly satisfactory way by saying that it is simply a form that energy may assume while undergoing transformation from the mechanical or the chemical form to the heat form, or the reverse.

ELECTRIC ENERGY.

A current of electricity is always accompanied by a magnetic field of peculiar form. Magnetism alone cannot produce electricity. Electricity can do work; magnetism cannot do work in the same sense—and alike with electricity, neither can it exist without contact with matter.

Ques. What is it convenient to consider, relating to these minute bodies?

Ans. That they are perpetually in motion with incredible velocities.

Ques. How is energy transmitted from one part of material substance to another?

Ans. Gradually and successively. It requires a medium and it requires a certain time.

Ques. What is the principal use or function in mechanics of electricity?

Ans. It is purely that of transmission. It corresponds to ropes, shafts and fluids as a medium of conveying and translating power or work.

NOTE.—It is evident that a body in motion has the capacity to do work, and a body at rest may also have the capacity to do work. In the first instance energy is of that kind which is due to the fact that the body is in motion, and has weight, and in the second, energy is due to the position or condition of a body at rest. The fly-wheel of a steam engine in motion possesses kinetic energy; a heavy weight at the top of a high tower possesses potential energy.

Kinetic energy is energy due to matter being actually in motion, or Energy of Motion—Dynamic-energy.

Potential or Static energy is a capacity for doing work due to advantage of position or other cause. A ten-pound weight supported one foot above a plane has ten foot-pounds of mechanical energy.

Electro-Motive Force.

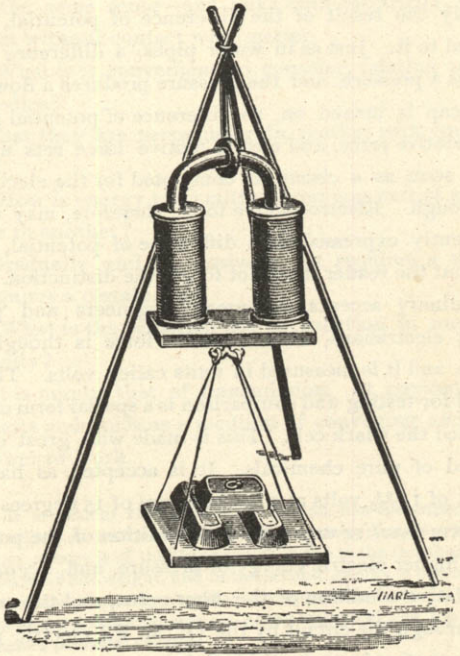
The term is employed to denote that which moves or tends to move electricity from one place to another. For brevity we sometimes write it E. M. F. In this particular case, it is obviously the result of the difference of potential, and proportional to it. Just as in water pipes, a difference of level produces a pressure, and the pressure produces a flow so soon as the cap is turned on, so difference of potential produces electro-motive force, and electro-motive force sets up a current so soon as a circuit is completed for the electricity to flow through. Electro-motive force, therefore, may often be conveniently expressed as a difference of potential, and *vice versa;* but the reader must not forget the distinction.

In ordinary acceptance among engineers and practical working electricians, electro-motive force is thought of as pressure, and it is measured in units called volts. The usual standard for testing and comparison is a special form of voltaic cell, called the Clark cell. This is made with great care and composed of pure chemicals. It is accepted as having an E. M. F. of $1\frac{434}{1000}$ volts at a temperature of 15 degrees C.

The term *positive* expresses the condition of the point having the higher electric energy or pressure, and, *negative*, the lower relative condition of the other point, and the current is forced through the circuit by the (E. M. F.) electric pressnre at the generator, just as a current of steam is impelled through pipes by the generating pressure at the steam-boiler.

NOTE.—Care must be taken not to confuse electro-motive force with electric force or electric energy, when matter is moved by a magnet, we speak rightly of magnetic force; when electricity moves matter, we may speak of eleetric force. But, E. M. F. is quite a different thing, not "force" at all, for it acts not on matter but on electricity, and tends to move it.

FIG. 15.



LIFTING POWER OF MAGNETS.

(See page 33.)

PRIMARY BATTERIES.

An electrical battery is the simplest method of generating electricity for practical use. Batteries all generate electricity by chemical action; the great variety being caused by the variation of the simple elements used in all.

The growing demand for electrical apparatus in workshops, power plants, office and public buildings and dwellings indicates the needs of plain instructions whereby the engineer, electrician or other mechanic can arrange or manage in a practical way the special devices ordinarily used.

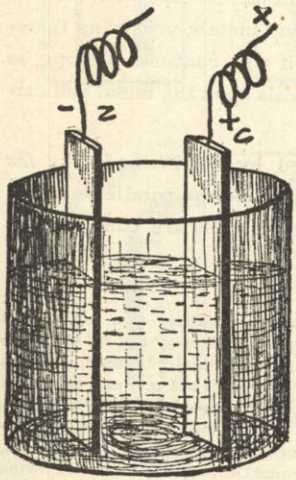


FIG. 16.

Batteries can be bought from supply houses all complete and ready to be set up, but the following pages of description and illustration will be found most useful.

Fig. 16 represents a simple voltaic cell.

The one fundamental fact on which the electro-chemical generation of current depends is that, if a plate of metal is placed in a liquid called an electrolyte, there is a dif-

erence of electrical condition produced between them of such sort that the metal either takes a lower or a higher electrical potential than the liquid, according to the nature of the metal and the liquid. If two different metals are placed in one electrolytic liquid, then there is a difference of state produced between them, such that, if joined by a wire outside the liquid, a current of electricity traverses this wire. This current proceeds in the liquid from the metal which is most acted upon chemically to that which is least.

The term battery is applied to a device in which one or more chemical substances in a fluid mixture act upon a metal and a carbon, or upon two different metals, producing thereby a current of electricity, which will continue as long as there is any action of the chemicals upon the metal and carbons, or upon the two metals.

Battery connections are formed by two methods; by *the series method*, as shown in Fig. 17, and the parallel method, Fig. 18. It will be observed that the cells are connected by their electrodes.

NOTE.—"The popular notion of a secondary battery as a contrivance for storing up electricity is quite erroneous. Energy can be stored up but not electricity, and hence, if the term 'accumulator' is used, it should be in the sense of an accumulator of energy. It is not very easy to draw a distinction between what should be properly called primary and what should be called secondary batteries. In both forms, energy is accumulated in a manner capable of being transformed into electric current, and, in both, this ultimately depends on chemical attraction; but, in the forms of battery, usually called secondary, the chemical processes are such that they can be conveniently and effectively reversed by an external source of current, and so put back the elements into an active condition, without very serious loss of available energy in so doing."—FLEMMING.

PRIMARY BATTERIES.

The quantity of electricity generated is precisely the same in each method of connecting up, but the effects are quite different. The series gives high electric pressure and small volume of current, while the parallel gives low electrical pressure and large volume of current.

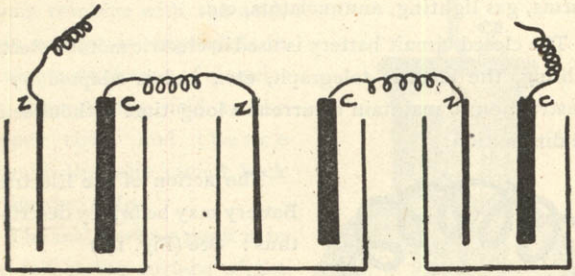


FIG. 17.

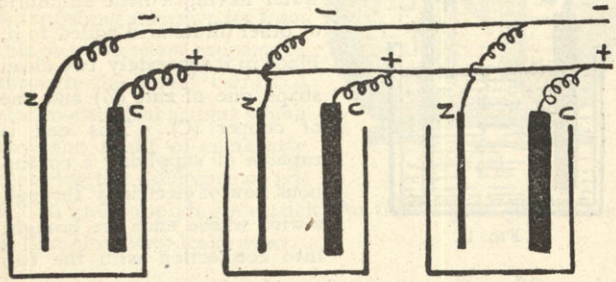


FIG. 18.

Batteries for producing electricity are divided into two classes :

1. Open circuit batteries.
2. Closed circuit batteries.

PRIMARY BATTERIES.

An open circuit battery is one adapted by its construction to maintain a current that shall not run down or exhaust itself when left on open circuit; for instance, where the electricity is not required constantly without intermission. This system is used in telephones, electric bells, burglar alarms, gas lighting, annunciators, etc.

The closed circuit battery is used in electric motors, electric lighting, the electric telegraph, etc., and is adapted by its construction to maintain a current a long time without sensible diminution.

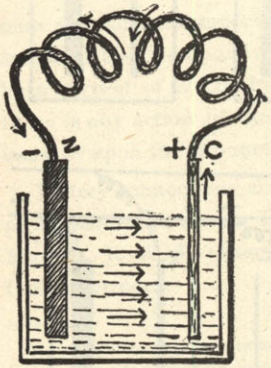


FIG. 19.

The action of the Electrical Battery may be briefly described thus: See (Fig. 19.)

Place in a glass jar some water having a little sulphuric or other dilute acid added to it. Place in it separately two clean strips, one of zinc (Z) and one of copper (C). This cell is capable of supplying a continuous flow of electricity through a wire whose ends are brought into connection with the two strips. When the current flows the zinc strip is observed to waste away, its consumption in fact furnishes the energy required to drive the current through the cell and the connecting wire. The cell may therefore be regarded as a kind of chemical furnace in which the fuel is the zinc.

PRIMARY BATTERIES.

If the strips are made to touch, or are joined by a pair of metal wires, immediately there is a rush of electricity, through the metal from the copper to the zinc, and a small portion of the zinc is at the same time dissolved away; the zinc parting with its latent energy as its atoms combine with the acid. This energy is expended in forcing a discharge of electricity through the acid to the copper strip, and thence through the wire circuit back to the zinc strip.

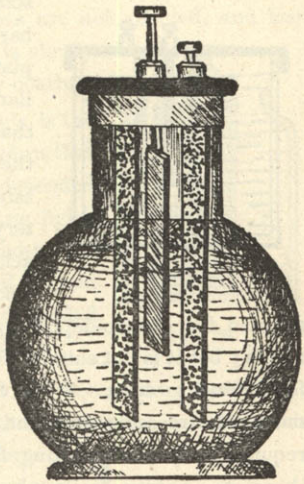


FIG. 20.

The real starting point is in the cell at the surface of the zinc where the chemical action is furnishing energy; for from this point there are propagated through the liquid certain electro-chemical actions which have the result of constantly renewing the difference of potential and supplying electricity to the + pole just as fast as that electricity leaks away.

ELECTRIC BATTERIES.

Smee's Battery is shown in Fig. 21; it is frequently termed the Smee Cell. It was devised in the year 1830 by Alfred Smee, an English electrician, and has been very extensively used, and consists of a platinized silver plate for the negative

element, with zinc plates for the positive. The platinized silver plate is usually attached to a wooden bar, and the zinc plates, placed one on each side of it, are kept in position by a metallic cramp passing over the top of the bar. A binding screw, passed through the wooden bar and attached to the silver plate, forms the anode, and a similar binding screw, on the cramp that holds the zincs to the bar, is the cathode. An earthenware containing-vessel is required; the battery is excited by dilute sulphuric acid (7 volumes of water to one of acid). This battery is admirably adapted for electro-depositing and general galvanic experiments; but it is not suitable for producing electric light, nor for intensity coils. It is easily managed, tolerably constant, and requires only one exciting fluid; therefore, porous cells are dispensed with.

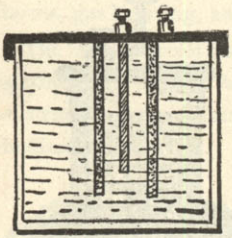


FIG. 21.

The Bunsen Cell, or Battery, shown in Fig. 22 is a two-fluid cell constructed with zinc and carbon electrodes. The negative plate is carbon, the positive plate amalgamated zinc. The excitant is a dilute solution of sulphuric acid. The top part of the carbon is sometimes impregnated

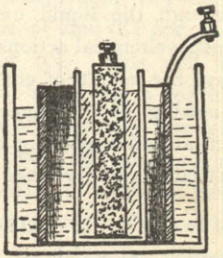


FIG. 22.

with paraffin wax to keep the acid from creeping up, and electrotyped with copper.

The force of the Bunsen increases after setting up for about an hour, and the full effect is not attained until the acid soaks through the porous cell. Carbons are not effected, and last any length of time. The zinc is slowly consumed, through the mercury coating.

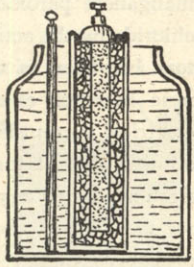


FIG. 23.

"With one exception, Bunsen's is the only real producer of voltaic currents that can be cheaply applied and depended upon in the production of electric light. Its current, once started, is almost constant for about four hours, and a good light may, with confidence, be depended upon for three hours."—URQUHART.

The Leclanché Battery or cell was invented by Leclanché, a French electrician, and was the first battery cell in which sal-ammoniac was used. This form of battery, Fig. 23, is in very general use for electric bells, its great recommendation being that, once charged, it retains its power without attention for several years. Two jars are employed in its construction; the outer one is of glass, contains a zinc rod, and is charged with a solution of ammonium chloride (sal ammoniac).

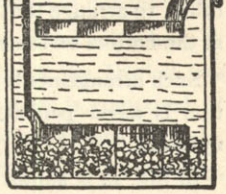


FIG. 24.

The inner jar is of porous earthenware, contains a carbon

plate, and is filled up with a mixture of manganese peroxide and broken gas carbon. When the carbon plate and the zinc rod are connected, a steady current of electricity is set up, the chemical reaction which takes place being as follows: The zinc becomes oxidized by the oxygen from the manganese peroxide, and is subsequently converted into zinc chloride by the action of the sal-ammoniac. After the battery has been in continuous use for some hours, the manganese becomes exhausted of oxygen, and the force of the electrical current is greatly diminished; but if the battery be allowed to rest for a short time, the manganese obtains a fresh supply of oxygen from the atmosphere, and is again fit for use. After about 18 months' work, the glass cell will probably require recharging with sal-ammoniac, and the zinc rod may also need renewing; but should the porous cell get out of order, it is better to get a new one entirely than to attempt to recharge it.—DYER.

Gravity Cells or batteries (see figure 24). Instead of employing a porous cell to keep the two liquids separate, it is possible, where one of the liquids is heavier than the other, to arrange that the heavier liquid shall form a stratum at the bottom of the cell, the lighter floating upon it.

Such arrangements are called *gravity cells*, but the separation is never perfect, the heavier liquid gradually diffusing upwards.

In Fig. 24 is shown the method which has been adopted of placing the zinc in the upper part of the cell and the copper in the lower part. The solution of the zinc sulphate which

surrounds the zinc is lighter than the copper sulphate which surrounds the copper. Fig. 25 represents the "Crowfoot" Gravity Battery, largely used for Telegraph and closed circuit work.

After the cell is set up sufficient time must be allowed to form these two sulphates before free action is attained.

The Daniell Battery consists of a copper cylinder containing another of porous earthenware, in which is placed a zinc rod; this latter forms the positive and the copper the negative element. The battery requires 2 excitants—a saturated solution of copper sulphate in the copper cylinder, and dilute sulphuric acid (1 volume oil of vitriol to 7 of water) in the porous cell. The walls of the latter keep the solutions separate, while allowing the electric current to pass through.

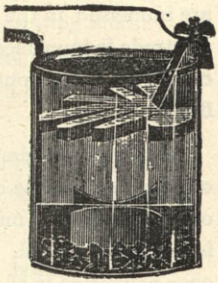


FIG. 25.

The cathode and anode are formed by attaching binding screws to the zinc rod and copper cylinder. The battery requires no frame, is effective in use, constant, and gives a current of fair intensity.

Latimer Clark's Standard Cell.—A standard cell whose E. M. F. is even more constant than that of the Daniell was suggested by Latimer Clark. This battery is composed of pure mercury, on which floats a paste of mercurous sulphate, a plate of zinc resting on the paste. Contact with the mercury, which acts as the positive pole, is made with a platinum wire. The E. M. F. is 1.436 legal volts.

DEFINITIONS RELATING TO PRIMARY BATTERIES.

The Voltaic-cell is very commonly called the voltaic battery after its discoverer, Volta, and more recently named the primary battery, to distinguish it from the secondary or storage battery.

A cell consists of a vessel containing a liquid in which two elements are immersed. In *One Fluid* cells both electrodes are immersed in the same solution. In *Two Fluid* cells each electrode is immersed in a separate solution, one of which is contained in a porous cup which is then immersed in the other liquid.

Dry cells are similar in construction to the open circuit, one fluid cell. The only difference being that starch or some other absorbent is mixed with the liquid forming a jelly which is not easily spilled. The dry cell is very efficient, but when once exhausted is of no further use.

All dry cells should have vent holes.

The Electrodes of a Primary Battery are the plates of metal or other substance immersed in the liquid. The zinc plate is called the generating electrode and the other plate the conducting electro. The latter is usually made of carbon, copper being the next most commonly used.

NOTE.—The plates in a galvanic couple are termed elements as the carbon and zinc plates in cell. The plate unattacked by the solution as the carbon plate in the above battery is termed the negative plate or element; the one attacked, as the zinc plate, is termed the positive plate or element.

DEFINITIONS—PRIMARY BATTERIES.

The Poles of a battery are the parts of the Electrodes which project out of the liquid. They are distinguished from each other by + for the positive and — for the negative pole. The terms *Pole* or *Terminal* apply to the ends of a break in any electric circuit.

The Exciting Fluid is the liquid which when plates are placed in it acts upon the plates and produces a current in a wire joining the two plates.

The electrolyte is another term for the exciting fluid.

The Anode is the plate which the current leaves to enter the liquid of the cell as it flows through the circuit of that battery.

The Kathode (or Cathode) is the plate the current enters as it leaves the liquid of the cell as it flows through the circuit of that battery.

Polarization is the weakening of the battery current by means of local action ; this is commonly caused by the collection of hydrogen bubbles on the copper plate. Polarization is overcome in two ways, namely, chemically and mechanically. In the first mentioned a solution or substance which will absorb the free hydrogen is introduced in the cell. In the second the plates have a roughened surface and are kept moving in the solution.

Local Action.—When the circuit is not closed the current cannot flow, and there should be no chemical action so long as the battery is producing no current. The impure zinc of commerce, however, does not remain quiescent in the acid,

but is continually dissolving and giving off hydrogen bubbles, causing local action. The impurities in the zinc consists of particles of iron, arsenic, and other metals.

Separating the elements.—Obviously the positive and negative elements of a battery must not be in contact within the exciting fluid; they should be separated by a space of ⅜ to ½ inch. In the case of batteries without porous cells, periodical attention will need to be given to ensure this condition being maintained.

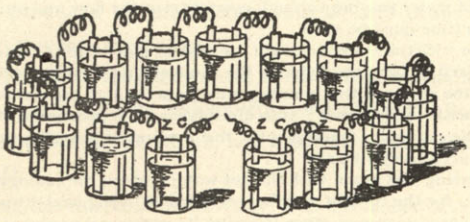
Electrolysis is the decomposition of a chemical compound by the electric current.

Bichromate Batteries of bottle shape as in Fig. 20, with two carbon plates, a sliding rod and movable zinc plate, are very extensively used by experimenters and lecturers, because they are always ready for being put to work with one motion of the hand, not necessitating any other preparation; and as soon as the desired result is obtained, the battery can be put out of action with the same facility.

MANAGEMENT AND CARE OF BATTERIES.

Cleanliness in the battery-room is essential to the best results. The jars, before being used, should be coated with parafine wax for an inch or so from the top. This prevents "creeping" of the salts and consequent weakening of the battery fluid. Zincs and coppers, or their homologous elements, should be thoroughly cleaned every time the cell is taken out of use. The zinc, after being thoroughly cleaned, should be rubbed with a little mercury. This prevents local action. Porous cups should be soaked in clean water four or five hours and then wiped dry. If the cells are cleaned and put away ready for use, when the emergency does come, the time spent in cleaning will never be regretted.

FIG. 26.



THE CROWN OF CAPS.

THE MAGNETIC AND ELECTRIC CURRENT.

This branch of science comes naturally under the head of Current Electricity, but,

To give a definition of the electric current is like attempting to describe something which every one knows about; it can be said to be simply the flow of electric energy from a point of high pressure to that of a lower, yet it must be owned that until we know with absolute certainty what electricity is we cannot expect to know precisely what a current of electricity is.

NOTE—The circuit may be compared to a system of hot-water pipes; in a hot water system there is a steam boiler, a flow and a return circulating pipe with pipe coils, at various points for giving off heat where warmth is required.

In an electric installation the dyamo or battery replaces the boiler; flow and return pipes are represented by the two conducting mains and the pipe-coils by lamps, motors and other apparatus.

In a hot-water system it is perfectly evident that whatever may be the quantity of water leaving the boiler, the same must return to it and the quantity of water passing through every part of the flow and return pipes in a given time must be alike.

It is so with the electric current; whatever may be the quantity of the current starting from the dynamo the same quantity comes back to it.

Also, the whole of this quantity must pass through the mains, but it is different with the pressure; this diminishes in proportion to the work done by the current. Consequently the pressure diminishes as the current advances along its path.

Comparing this again with the hot-water system, the analogy is fairly complete; for the current may be regarded as losing heat (this is often disguised) as it advances, since in losing its pressure it produces heat and the hot water does the same.

MAGNETIC AND ELECTRIC CURRENT.

Ques.—In cases where part of the electricity is transferred from the body originally electrified to the body touched what is this transfer of electricity called?

Ans.—It is called a discharge.

Ques.—When does a discharge of electricity become a current?

Ans.—When electricity is supplied to the body as fast as it is taken away.

In considering the practical questions relating to the electric current three characteristic effects need to be thought of:

1. The chemical.
2. The thermal (heat).
3. The magnetic.

All lines of magnetic force from closed circuits and an electric circuit, so called, may be said to be the path in which electricity passes from a given point around a conducting point back again to its starting point.

The discovery of electric currents originated with Galvani, a physician of Bologna, who about the year 1786, made a series of curious and important observations upon the convulsive motions produced by the "return shock" and other electric discharges upon a frog's leg.

This immortal discovery arose in the most immediate and direct manner, from an indisposition with which a Bolognese lady was effected, for which her medical adviser prescribed *frog-broth*.

Galvani, the husband of the lady, was Professor of Anatomy in the University of Bologna. It happened that several frogs,

prepared for cooking, lay upon the table of his laboratory, near to which his assistant was occupied with an electrical machine. On taking sparks from time to time from the conductor, the limbs of the frogs were affected with convulsive movements resembling vital actions.

This was the effect of the inductive action of the electricity of the conductor upon the highly electroscopic organs of the frogs; but Galvani was not sufficiently conversant with this branch of physics to comprehend it, and consequently regarded it as a new phenomenon. He proceeded to submit the limbs of frogs to a course of experiments, with the view to ascertain the cause of what appeared to him so strange. For this purpose, he dissected several frogs, separating the legs, thighs, and lower part of the spinal column from the remainder so as to lay bare the lumbar nerves. He then passed *copper* hooks through that part of the dorsal column which remained above the junction of the thighs, without any scientific object, but merely for the convenience of suspending them until required for experiment. It chanced, also, that he suspended these *copper* hooks upon the *iron* bar of the balcony of his window, when to his inexpressible astonishment, he found that whenever the wind or any other accidental cause brought the muscles of the leg into contact with the iron bar, that a similar convulsive kick was produced in the frog's leg.

Galvani imagined this action to be due to electricity generated by the frog's leg itself. It was, however, proved by Volta, Professor in the University of Pavia, that the electricity arose not from the muscle or nerve, but from the contact of

the dissimilar metals. A greater accumulation of electric energy at one point than at another is what causes the electric current. Such a current always flows through a conducting body if the ends are kept at a different electrical pressure.

In order that a continuous flow may be kept up there must be a circuit provided. Currents are called *continuous* if they flow without stopping in one direction. They are called *alternate currents* if they continually reverse in direction in a regular periodic manner, flowing first in one direction round the circuit and then in the other.

The flow would cease unless the difference in electric pressure is maintained; this can be done by either a battery or dynamo. The current is impelled through the circuit by the electric pressure at the battery or dynamo just as a current of steam is impelled through pipes, of whatever form, by the pressure of the steam formed in the boiler.

All dynamos, of whatever form, are based upon the discovery made by Faraday in 1831, that electric currents are generated in conductors by moving them in a magnetic field. Faraday's principle may be enunciated as follows: "When a conductor is moved in a field of magnetic force in any way so as to cut the lines of force, there is an electromotive-force produced in the conductor, in a direction at right angles to the direction of the motion, and at right angles also to the direction of the lines of force, and to the right of the lines of force, as viewed from the point from which the motion originates."

To understand clearly Faraday's principle—that is to say, how is it that the act of moving a wire so as to cut magnetic

lines of force can generate a current of electricity in that wire —let us repeat and further explain this.

A wire through which a current of electricity is flowing looks in no way different from any other wire. No man has ever yet seen the electricity running along in a wire, or knows

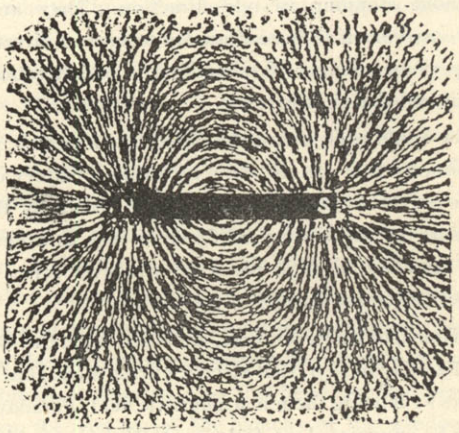


FIG. 27.

precisely what is happening there, but no electrician is in any doubt as to one most vital matter, namely, that when that which is called an electric current flows through a wire, the magnetic forces with which that wire is thereby, for the time, endowed, resides not in the wire at all, but in the space surrounding it. Every one knows that the space or "field" surrounding a magnet is full of magnetic "lines of force."

and that these lines run in tufts from the N-pointing pole to the S-pointing pole of the magnet, invisible until, by dusting iron filings into the field, their presence is made known, though they are always in reality there (Fig. 27). A view of the magnetic field at the pole of a bar magnet, as seen end-on, would, of course, exhibit merely radial lines, as seen in Fig. 28.

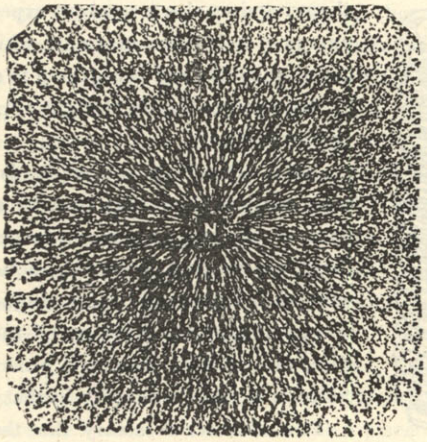
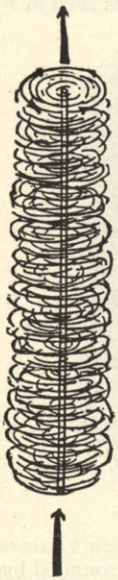


FIG. 28.

Now, every electric current (so-called) is surrounded by a magnetic field, the lines of which can be similarly revealed. To observe them, a hole is bored through a card or a piece of glass, and the wire which carries the current must be passed up through the hole. When iron filings are dusted into the field they assume the form of concentric circles (Fig. 12),

showing that the lines of force run completely round the wire, and do not stand out in tufts. In fact, every conducting wire is surrounded by a sort of magnetic whirl, like that shown in Fig. 29. A great part of the energy of the so-called electric current in the wire consists in these external magnetic whirls. To set them up requires an expenditure of energy; and to maintain them requires also a constant expenditure of energy. It is these magnetic whirls which act on magnets and cause them to set as galvanometer needles do at right angles to the conducting wire.

FIG. 29.



MAGNETIC WHIRL SURROUNDING WIRE CARRYING CURRENT.

Now, Faraday's principle is nothing more nor less than this: that by moving a wire near a magnet across a space in which there are magnet lines, the motion of the wire, as it cuts across those magnetic lines, sets up magnetic whirls round the moving wire, or, in other language, generates a so-called current of electricity in that wire.

It is however necessary that the moving conductor should, in its motion, so cut the magnetic lines as to alter the number of lines of force that pass through the circuit of which the moving conductor forms part. If a conducting circuit—a wire ring or single coil, for example—be moved along in a uniform magnetic field, so that only the same lines of force pass through it, no current will be generated, see Fig. 30. Or if, again, as in

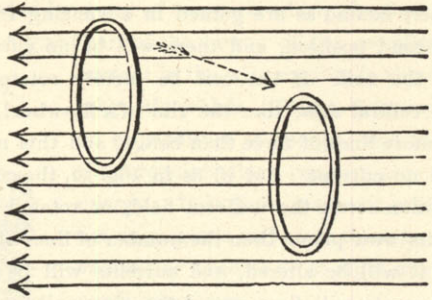
MAGNETIC AND ELECTRIC CURRENT.

Fig. 31, the coil be moved by a motion of translation to another part of the uniform field, as many lines of force will be left behind as are gained in advancing from its first to its second position, and there will be no current generated in the coil. If the coil be merely rotated on itself round a central axis, like the rim of a fly-wheel, it will not cut any more lines of force than before, and this motion will generate no current. But if, as in Fig. 32, the coil be tilted in its motion across the uniform field, or rotated round any axis in its own plane, then the number of lines of force that traverse it will be altered, and currents will be generated. These currents will flow round the ring coil in the right-handed direction (as viewed by a person looking along the magnetic field in the direction in which the magnetic lines run) if the effect of the movement is to diminish the number of lines of force that cross the coil; they will flow round in the opposite sense, if the effect of the movement is to increase the number of intercepted lines of force.

If the field of force be not a uniform one, then the effect of taking the coil by a simple motion of translation from a place where the lines of force are dense to a place where they are less dense, as from position 1 to position 2 in Fig. 32, will be to generate currents. Or, if the motion be to a place where the lines of force run in the reverse direction, the effect will be the same, but even more powerful.

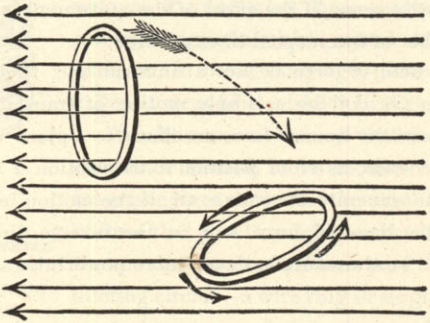
MAGNETIC AND ELECTRIC CURRENT.

FIG. 30.



CIRCUIT MOVED WITHOUT CUTTING ANY LINES OF FORCE

FIG. 31.



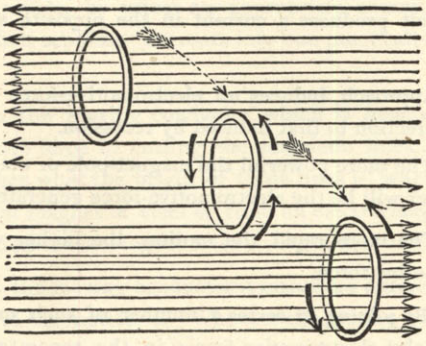
CIRCUIT MOVED SO AS TO ALTER NUMBER OF LINES OF FORCE THROUGH IT.

MAGNETIC AND ELECTRIC CURRENT.

We may now summarize the points under consideration and some of their immediate consequences, in the following manner:

(1.) A part, at least, of the energy of an electric current exists in the form of magnetic whirls in the space surrounding the conductor.

FIG. 32.



(2.) Currents can be generated in conductors by setting up magnetic whirls round them.

(3.) We can set up magnetic whirls in conductors by moving magnets near them, or moving them near magnets.

NOTE.—As a matter of fact, it would be impossible to have a magnetic field exactly like Fig. 32; for, in the intermediate part, between the upper and lower fields, the magnetic lines would be of curved complex form.

(4.) To set up such magnetic whirls, and to maintain them by means of an electric current circulating in a coil, requires a continuous expenditure of energy, or, in other words, consumes power.

(5.) To induce current in a conductor, there must be relative motion between conductor and magnet, of such a kind as to alter the number of lines or force embraced in the circuit.

(6.) Increase in the number of lines of force embraced by the circuit produces a current in the opposite sense to decrease.

(7.) Approach induces an electromotive-force in the opposite direction to that induced by recession.

(8.) The more powerful the magnet-pole or magnetic field the higher will be the electromotive-force generated.

(9.) The more rapid the motion, the higher will be the electromotive-force.

(10.) By joining in series a number of such moving conductors, the electromotive-forces in the separate parts are added together; hence very high electromotive-forces can be obtained by using numerous coils properly connected.

(11.) Since the quantity or strength of the currents depends on the resistance of the conductors in the circuit, as well as on the electromotive-force, all unnecessary resistance should be avoided.

(12.) Approach being a finite process, the method of approach and recession (of a coil towards and from a mag-

net pole) must necessarily yield currents alternating in direction.

(13.) By using a suitable commutator, all the currents, direct or inverse, produced during recession or approach, can be turned into the same direction in the wire that goes to supply currents to the external circuits; and if the rotating coils are properly grouped so that before the electromotive-force in one set has died down another set is coming into action, then it will be possible, by using an appropriate commutator, to combine their separate currents into one practically uniform current.

(14.) To the moving conductor which is generating the electromotive-force by cutting the magnetic lines, it makes no difference what the origin of those lines is, whether from a permanent magnet of steel or from an electro-magnet, provided the number of magnet lines so cut is the same.

(15.) To the moving conductor it makes no difference what the origin of the motion is. Whether the motion be due to a steam engine, or to a gas engine, or to hand driving, or to the driving of an electric current in the wire itself (as in the case of electric motors), it makes no difference to the moving conductor, which provided that the speed and the number of magnet lines given will generate the same electromotive-force.

ANIMAL ELECTRICITY.

Animal Electricity.—Several species of cretures inhabiting the water have the power of producing electric discharges by certain portions of their organism. The best known of these are the *Torpedo*, the *Gymnotus*, and the *Silurus*, found in the Nile and the Niger. The Electric Ray, of which there are

THE ELECTRIC EEL.

three species inhabiting the Mediterranean and Atlantic, is provided with an electric organ on the back of its head, as shown in illustration on this page. This organ consists of laminæ composed of polygonal cells to the number of 800 or 1000, or more, supplied with four large bundles of nerve fibres; the under surface of the fish is —, the upper +. In the Surinam eel, the electric organ goes the whole length of the body along both sides. It is able to give a most terrible shock, and is a formidable antagonist when it has attained its full length of 5 or 6 feet.

"POINTS" RELATING TO THE ELECTRIC CURRENT.

To designate the character of a current, and also a current with reference to its origin, various terms are used. Battery current, dynamo current, earth current, etc. These are terms used to designate the current from a battery, a dynamo or currents flowing through the earth on account of difference of potential at different points.

When a difference of electrical force or pressure exists in two places connected by a conductor, or a series of conducting bodies. a current will flow between the two points. The difference of force may be due to several causes, but whatever the cause the current will flow. The two places may be a few inches apart, as in a wire from a primary battery, or miles apart, as in a transmission system, or in the currents of the earth or air. They may be connected by a small copper wire, the rails of a street railway, or by a combination of a large number of conducting bodies. This conductor may be of large capacity, of low resistance, or may be a poor conducting medium.

Two kinds of current are generated, distinguished by the direction which they flow. The continuous or direct current

which flows continuously in one direction, and the alternating reversed current, which alternates the direction of its flow are the currents used. and these two kinds include a number of classes.

The alternating current may alternate the direction in which it flows ten thousand times a second, or twenty-five times a second; this is called the frequency of its alternations.

A constant current is an unvarying current. Although the voltage may vary the amount of current does not change. In series arc lighting systems the current is universally constant.

The quantity of electricity conveyed by a current is proportional to the current and the time it continues to flow.

NOTE.—The telegraphers have made a series of tests for the purpose of ascertaining the actual amount of time which elapses while a signal is being flashed from America to Europe along the Atlantic cable. The tests referred to were made at the McGill University, Montreal, Canada, in June, 1891. In carrying out these experiments a duplex circuit was arranged on both land and sea along the entire line, which connects Montreal with Waterville, Ireland. When the line was "cleared" a chronograph was attached to the observatory wire at Montreal and everything declared in readiness. The instrument clicked off the signal, while the experimenters watched the chronograph with breathless interest. It did not seem to them "like an age of suspense," however, for within one and one-eighth seconds the chronograph recorded the return of the signal, while it slowly dawned upon the interested scientists present that the flash had actually made the round trip from Montreal to Ireland in a period of time but little greater than one-sixtieth of a minute. In that very short space of time, infinitesimal and almost unthinkable that electric message was flashed a distance almost as great as one-third the circumference of the world, or to be exact, 8,022 miles. Other experiments made the same day showed a variation of from one to 1.1 seconds for the signal to make a round trip.

ELECTRIC CURRENT.

The passage of a current through a conductor cannot be effected without a loss of power *i. e.*, diminished pressure.

Loss of power means work done; if this work has a useful purpose it is not a loss in the common sense of the word, but in all other cases it is waste. Thus, any pressure of the current used in a lamp is no loss and nearly the whole pressure of the current, in a well designed installation, may be regarded as utilized in passing through the lamps, motors and other apparatus, a system shown.

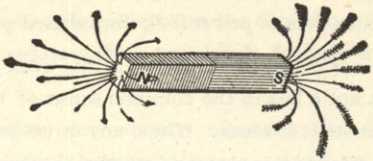
The electric current, like steam and water flows in the direction of the least resistance. This is a general statement, to be modified by the fact that where two or more paths exist some current will pass through each. See page 79, "Divided Currents."

The speed of the electric current has been quite accurately determined to be identical with that of light.

Experiments have demonstrated the remarkable fact that alternating currents of a tension ten times that which is used in electro-execution do not effect or injure the human body when passed through the same; and in fact are hardly perceptible in case the currents alternate 100,000 times in a second, that is, change their direction at this almost incomprehensible velocity.

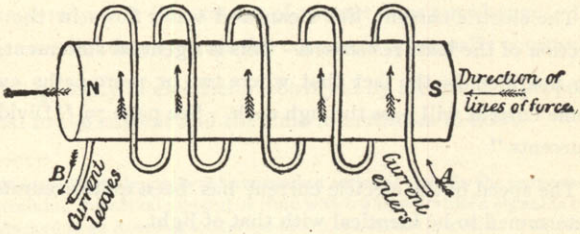
THE SOLENOID.

FIG. 33.



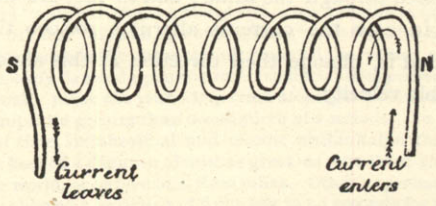
BAR MAGNET SHOWING LINES OF FORCE.

FIG. 34.



ELECTRO MAGNET SHOWING LINES OF FORCE.

FIG. 35.



SOLENOID SHOWING LINES OF FORCE.

THE SOLENOID.

Solenoids.—If a wire, while being traversed by an electric current, is wound up into a spiral coil, the arrangement becomes a "solenoid." (See Fig. 35.)

For with a long closely wound spiral, conveying a current, the lines of force are similar to those of a bar-magnet. (See Fig. 33.) These lines of force must be thought of as closed loops linked with the current. The conductor conveying the current passes through all the loops of force, and these are, so to speak, threaded or slung on the current line of flow. It will be readily inferred that since a solenoid of wire conveying a current attracts and repels by its extremities the poles of a magnet, two such spiral conductors conveying currents should attract and repel each other. This is found to be the case.

The lines of force form continuous closed curves running through the interior of the coil, and issuing from one end and entering into the other end of the coil, and that the arrangement of the external magnetic field is very similar to that of a permanent bar magnet of cylindrical form as represented in Fig. 34.

A solenoid has north and south poles, and in fact possesses all the properties of an ordinary permanent magnet, with the important difference that the magnetism is entirely under control, for it is found that under all circumstances the strength of the magnetic field of a solenoid is at every point proportional to the strength of the electric current passing through its coils; if the current is increased, the magnetism is increased in proportion also; and if the current is stopped,

all trace of magnetism disappears. The magnetic effect or the magnetising power of a solenoid is also proportional to the number of turns of wire composing the coil.

As previously mentioned, the strength of the magnetic field of a solenoid is strictly proportional to the strength of the current flowing in its coils; this, however, is no longer true when the solenoid is provided with an iron core or becomes an electro magnet, for the reason that the magnetic properties of the iron alters with the strength of the magnetic field.

At first, the presence of the iron enormously increases the strength of the field; after a time, however, as the strength of the current flowing in the exciting coils is increased, the conductibility of the iron for the lines of force appears to decrease, until a point is eventually reached when the presence of the iron core appears to have no effect whatever in increasing the strength of the field.

At this stage the iron core may be regarded as being *saturated* with lines of force, and any further increase of magnetising power will produce only a slight increase in the strength of the field, any such increase being that due to the effect of the coils alone acting merely as a simple solenoid.

Current Sheets—When a current enters a solid conductor it no longer flows in one line but spreads out and flows through the mass of the conductor. When a current is led into a thin plate of conducting matter it spreads out into a "current sheet" and flows through the plate in directions that depend upon the form of the plate and the position of the pole by which it returns to the battery.

CURRENT SHEETS.

Thus, if wires from the two poles of battery are brought into contact with two neighboring points in the middle of a very large flat sheet of tinfoil, the current flows through the foil not in one straight line, but in curving "lines of flow," which start out in all directions and curl round to meet in curves very like those of the "lines of force" that run from the N pole to the S pole of a magnet (Fig. 14). When the earth is used as a return wire to conduct the telegraph currents, a similar spreading of the currents into current sheets occurs.

Divided Circuits.—If a circuit divides into two branches, uniting together again, the current will also be divided, part flowing through one branch part through the other. *The relative strengths of current in the two branches* will be proportional to their conductivities, *i. e.*, *inversely proportional to their resistances.*

Direction of Lines of Electrical Force.—The direction of the lines of force is found at any spot by holding a small magnetic test-needle at that point and noting the direction in which it sets, and the direction of its marked or north pole.

Various rules have been given for recollecting the direction of the current induced in a conductor when moved so as to cut lines of magnetic force and alter the amount of magnetic induction passing through the circuit. These rules depend generally on some association with the position and motion in swimming, or upon the direction of the cardinal points and the motion of the sun, earth, etc. Apart from the difficulty of recollecting the rules themselves, it requires an effort of

imagination to apply them to the case of an armature, bar or wire, disc or loop, and as a means of economising time and brain labor the following rule by Prof. Flemming has been found very useful.

"If any circuit is being moved in a magnetic field, and it is required to know the direction in which electricity is being urged in any portion of the circuit which is cutting lines of force, proceed as follows: Hold the first and middle fingers and thumb of the right hand in a position as nearly as possible at right angles to each other, so as to represent three axes in space. Make the following associations. Let the direction of the forefinger represent the direction of the lines of force. Let the direction of the thumb represent the direction at right angles to the direction of the field in wich the element of the circuit is moving, then the direction of the *middle finger* represents the direction of the induced current." See Fig. 36.

In railroad work now becoming of primary importance, it is always understood that the current flows *out* on the trolley wire and *comes back* through the rail or by the return conductor connected to the rail. This return conductor being sometimes placed underground and some instances upon poles with underground connection to the rail every six or eight poles.

NOTE.—The following rule gives the relation of the electric current to the lines of magnetic force produced by it.

If you look at the positive (or north) end of an electro-magnet, the direction of the current setting up the magnetism is that of positive rotation. Similarly, if you imagine a section made in a conductor carrying a current and look at the positive end of this conductor (*i. e.*, the end from which the current is flowing) the direction of lines of force set up about

FLEMING'S RULE.

FIG. 36.

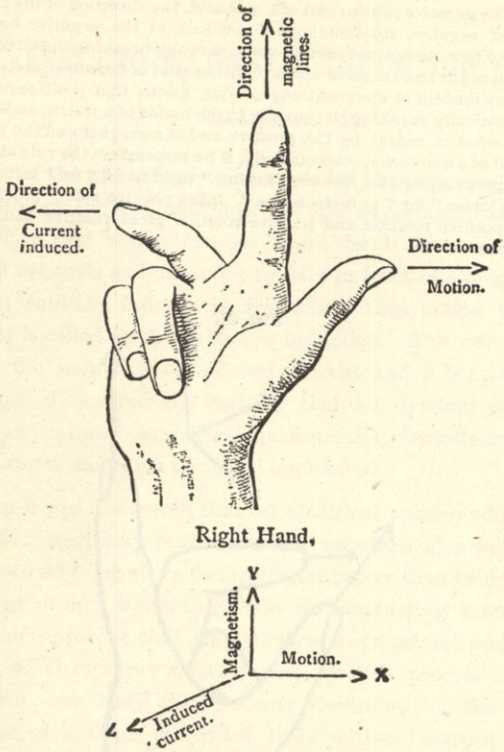


ILLUSTRATION OF FLEMING'S RULE.

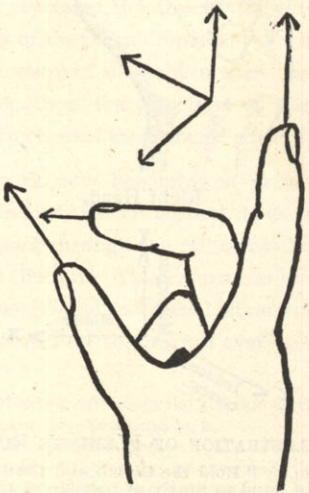
FLEMING'S RULE: "Hold the thumb and the first and the middle fingers of the right hand as nearly as possible at right angles to each other, as in Fig. 36, so as to represent three rectangular axes in space. If the thumb points in the direction of the motion, and the forefinger points along the direction of the magnetic lines, then the middle finger will point in the direction of the induced electro-motive force."

DIRECTION OF ELECTRIC CURRENT.

the conductor in the direction of positive rotation. Conversely, if you look at the negative (south) end of a solenoid, the direction of the current is that of negative rotation, and if you look at the negative end of a conductor (*i. e.*, imagine a section without really breaking the circuit) the direction of the lines of force about it will be that of negative rotation.

Every student of electrical engineering knows that positive rotation, mathematically speaking, is opposite to the hands of a watch, and he also knows what is meant by the positive end of a magnet and the positive terminal of a conductor. Accordingly, if he remembers the rule at all, he cannot make a mistake, like substituting "right hand" for "left hand," or "clockwise" for "anti-clockwise." It is a positive rule; positive and means positive rotation and positive rotation gives positive end.—B. S. LAMPHER.

FIG. 87.



ELECTRO-MAGNETIC INDUCTION.

One of the great discoveries made by Faraday was that of induction or induced currents. While experimenting with electricity and magnetism he found that if he took a wire, joined the ends and moved it rapidly in front of a magnet, a current would be induced in the wire. This action of the magnet is called electro-magnetic induction. The current is called the induction or induced current and it is upon this principle discovered by Faraday that all dynamo electric machinery is based, as well as induction coils, alternate current transformers and other electrical appliances.

When it was discovered that an electrical spark—which is a transient electric current—would not pass through a vacuum, that it would jump three feet in the air rather than bridge the eighth of an inch where there was no conducting material; it became apparent that empty space was a perfect non-conductor of electricity; nevertheless, by this process called induction, one body may become electrified by the mere presence of another electrified body without contact with it, just as a body may be heated by another body without contact.

When a wire, charged with a heavy current of electricity is strung parallel for a considerable distance to another wire,

upon which there is no electric current, or a much weaker current, the strongly-charged wire excites in the weaker wire a sympathetic current, which moves in the opposite direction, but vibrates, pulsates, and in all respects reproduces the manifestation of the current in the stronger wire. This is induction. The distance at which it will be produced varies with the intensity of the current, the atmosphere and the size of the wire.

An understanding of what is meant by induction is absolutely necessary to the explanation of the alternating system of incandescent lighting. In many instances of incandescent lighting the wires from the generating plant are carried to the outside only of the buildings to be lighted. There they are placed in a coil, in close proximity to, but not in contact with, another coil wire leading into the building. From the last-named coil, called the 'induction coil,' wires are carried to the glass bulbs, which we see on every hand, in which are placed carbonized loops.

Under the alternating system the incandescent lights in the buildings are produced, not by the introduction into the building of the original current, but by the sympathetic or induced current described above, set up in the induction coil from the passage of the direct current on the wire and coil outside the building.

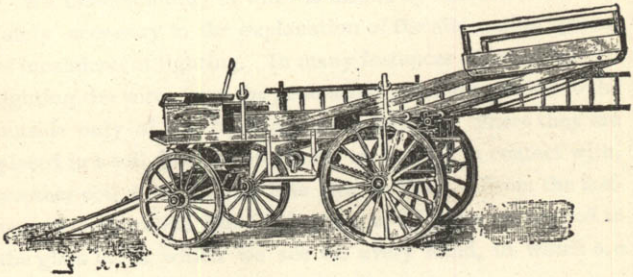
This influence, whatever its nature, by which the primary *induces* a current in a secondary circuit is not affected by the interposition of any sheet of material which is non-magnetic

ELECTRO-MAGNETIC INDUCTION.

and non-conducting. A wooden board, or a sheet of cardboard, or a sheet of india-rubber, does not prevent the induction; but a thick sheet of copper greatly diminishes the effect, and a plate of iron prevents it altogether.

Induction can occur only when the electrified body is insolated and it is impossible to insulate against it.

FIG. 39.



TOWER WAGON.

ELECTRICAL RESISTANCE.

Resistance is that which stops the flow of electricity.

The practical electrician has to measure electrical resistances, electro-motive forces, and the capacities of condensers. Each of these several quantities is measured by comparison with ascertained standards, the particular methods of comparison varying however, to meet the circumstances of the case.

Ohm's law shows us that the strength of a current due to an electro-motive force falls off in proportion as the resistance in the circuit increases. It is therefore possible to compare two resistances with one another by finding out in what proportion each of them will cause the current of a constant battery to fall off.

Silver is taken as the standard, with the percentage of 100 and the conductivity of all other metals is expressed in hundredths of the conductivity of silver.

NOTE.—A current of electricity always flows in a conducting circuit when its ends are kept at different potentials, in the same way that a current of water always flows in a pipe when a certain pressure of water is supplied. The same electrical pressure does not, however, always produce a current of electricity of the same strength, nor does a certain pressure of water always produce a current of water of the same volume or quantity. In both cases the strength or volume of the currents is dependent not only upon the pressures applied, but also upon the *resistance* which the conducting circuit offers to the flow in the case of electricity, and on the friction (which may be expressed as resistance) which the pipe offers to the flow in the case of water.

ELECTRICAL RESISTANCE.

The metals in general conduct well, hence their resistance is small, but metal wires must not be too thin or too long, or they will resist too much, and permit only a feeble current to pass through them. The liquids in the battery do not conduct nearly so well as the metals, and different liquids have different resistances. Pure water will hardly conduct at all, except for high potential electricity it is a fair conductor.

Salt and saltpetre dissolved in water are good conductors, and so are dilute acids, though strong sulphuric acid is a bad conductor. Gases are bad conductors.

Another very important fact concerning the resistance of conductors is, that the resistance of conductors in general increases with the temperature. While this fact is true regarding metals, with non-metals it is not true. The resistance of different metals does not increase in the same proportion. Iron at 100 degrees C, has lost 39 per cent of the conducting power it possessed at zero, while silver loses but 23 per cent.

It should be borne in mind that it is not really known what produces the quality of resistance any more than we really know the laws which govern the transmission of light and heat.

Laws of Electrical Resistance—Resistances in a circuit may be of two kinds—*first*, the resistances of the conductors themselves; *second*, the resistance due to imperfect contact at points. The latter kind of resistance is affected by pressure, for when the surfaces of two conductors are brought into more intimate contact with one another, the current passes more

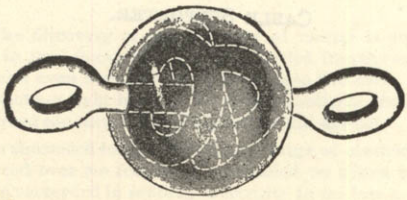
freely from one conductor to the other. The contact-resistance of two copper conductors may vary from infinity down to a small fraction, according to the pressure. The following are the laws of the resistance of conductors:

1. *The resistance of a conducting wire is proportional to its length.* If the resistance of a mile of telegraph wire be 13 ohms, that of fifty miles will be $50 \times 13 = 650$ ohms.

2. *The resistance of a conducting wire is inversely proportional to the area of its cross section,* and therefore in the usual round wires *is inversely proportional to the square of its diameter.* Ordinary telegraph wire is about $\frac{1}{6}$th of an inch thick; a wire twice as thick would conduct four times as well, having four times the area of cross section; hence an equal length of it would have only $\frac{1}{4}$th the resistance.

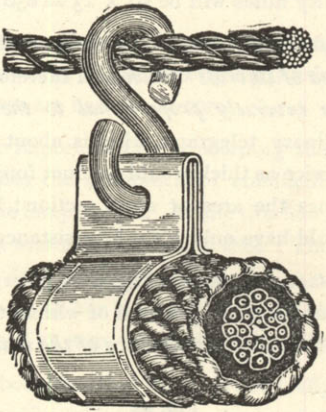
3. *The resistance of a conducting wire of given length and thickness depends upon* the material of which it is made—that is to say, upon the specific resistance *of the material.*

FIG. 40.



GLOBE STRAIN INSULATOR.

FIG. 41.



CABLE SUPPORTER.

CONDUCTORS AND NON-CONDUCTORS.

The manner in which electricity is communicated from one body to another depends on the conducting property of the body imparting and the body receiving it.

Bodies differ from each other in a striking manner in the freedom with which the electric current moves upon them. If the electric current be imparted to a certain portion of the surface of glass or wax, it will be confined strictly to that portion of the surface which originally receives it, by contact with the source of electricity; but if it be in like manner imparted to a portion of the surface of a metallic body, it will instantaneously diffuse itself uniformly over the entire extent of such metallic surface, exactly as water would spread itself uniformly over a level surface on which it is poured.

NOTE.—The discovery of this property of matter is due to Stephen Gray, who, in 1729, found that a cork, inserted into the end of a rubbed glass tube, and even a rod of wood stuck into the cork, possessed the power of attacking light bodies. He found, similarly, that metallic wire and pack-thread conducted electricity, while silk did not.

Gray even succeeded in transmitting a charge of electricity through a hempen thread over 700 feet long, suspended on silken loops. A little later, Du Fay succeeded in sending electricity to no less a distance than 1,256 feet through a moistened thread, thus proving the conducting power of moisture. From that time the classification of bodies into conductors and insulators has been observed.

CONDUCTORS AND NON-CONDUCTORS.

The former class of bodies, which do not give free motion to the electric fluid on their surface, are called non-conductors; and the latter, on which unlimited freedom of motion prevails, are called conductors.

Of all bodies, the most perfect conductors are the metals. These bodies transmit electricity almost instantaneously, without any sensible obstruction, provided their dimensions are not too small in relation to the quantity of electricity imparted to them.

Good non-conductors are also called insolators, but it will be apparent from what has been explained, that it would be more correct to designate bodies as good and bad conductors in various degrees, than as conductors or non-conductors. There exists no body which, strictly speaking, is either an absolute conductor or absolute non-conductor.

The bodies named in the following series possess the conducting power in different degrees in the order in which they stand, the most perfect conductor being first, and the most perfect non-conductor last in the list.

NOTE.—There are two apparent exceptions to the law that electricity resides only on the outside of conductors: (1.) If there are electrified insulated bodies actually placed inside the hollow conductor, the presence of these electrified bodies acts inductively and attracts the opposite kind of electricity to the inner side of the hollow conductor. (2.) When electricity flows in a current, it flows through the substance of the conductor. The law is limited, therefore, to electricity at rest—that is, to *statical* charges.

CONDUCTORS AND NON-CONDUCTORS.

Silver, . .	Good Conductors.
Copper, . .	
Other metal, .	
Charcoal, . .	
Water, . .	
The body, . .	Partial Conductors.
Cotton, . .	
Dry Wood, .	
Marble, . .	
Paper, . .	
Oils, . . .	Non-Conductors or Insulators
Porcelain, . .	
Wool, . .	
Silk, . . .	
Resin, . .	
Gutta-percha, .	
Shellac, . .	
Ebonite, . .	
Parraffin, .	
Glass, . .	
Dry air, . .	

The earth is a good conductor; much difficulty is frequently experienced by the wires making contact with some substance that will conduct the electricity to the earth. This is called "grounding."

NOTE.—Copper is preeminently the metal used for electric conduction, being at once among the best conductors, the most ductile, the strongest and the cheapest; in each of these respects it is excelled by one or more of the other metals, but no other approaches it in the average of all qualities.

CONDUCTORS AND NON-CONDUCTORS.

Electricity is transmitted, not like light and heat, through the interior dimensions of bodies, but only on their surfaces. This is proved by the fact that it is found to be immaterial to the distribution what the interior of a conductor is made of; it may be solid metal, or hollow, or even consist of wood covered with tin-foil or gilt, but, if the shape be the same, the charge will distribute itself precisely in the same manner over the surface. There are several ways of proving by direct experiment this very important fact.

Glass which is an almost perfect conductor of light, is a non-conductor of heat and electricity. Sealing wax, which is a non-conductor of electricity, is also a non-conductor of light and heat. The metals, on the other hand, are conductors of heat and electricity, but are non-conductors of light. Water is a conductor of electricity and light, but a non-conductor of heat.

The conducting power of bodies is affected in different ways by their temperature. In the metals it is diminished by elevation of temperature; but in all other bodies, and especially in liquids, it is augmented. Some substances, which are non-conductors in the solid state become conductors when fused. Sir. H. Davy found that glass raised to a red heat became a conductor; and that sealing-wax, pitch, amber, shell-lac, sulphur, and wax, became conductors when liquefied by heat.

If a conducting body which is insulated and charged with electricity, be brought into contact with another conducting body, which is also insulated and in its natural state, the elec-

tricity will diffuse itself over the surfaces of both conductors in proportion to their relative magnitudes.

The most perfect non-conductors lose their virtue if their surface be moist, the electricity passing by the conducting power of the moisture. This circumstance also shows why it is necessary to dry previously the bodies on which it is desired to develop electricity by friction.

Atmospheric air must manifestly belong to the class of non-ductors, for if it gave a free passage to electricity, the electrical effects excited on the surface of any body surrounded with it would soon pass away; and no electrical phenomena of a permanent nature could be produced, unless the bodies were removed from the contact of the air.

Air, however, when rarefied, loses in a great degree its non-conducting property; and an electrified body soon loses its electricity when placed in the exhausted receiver of an air-pump.

Water, whether in the liquid or vaporous form, is a conductor, though of an order greatly inferior to the metals. This fact is of great importance in electrical phenomena. The atmosphere, contains suspended in it, always more or less aqueous vapor, the presence of which impairs its non-conducting property.

If a current of electricity pass over a conductor, no change in the heat condition of the conductor will be observed so long as its transverse section is so considerable as to leave sufficient space for the free passage of the current. But, if its

thickness be diminished, or the quantity of electricity passing over it be augmented, or, in general, if the ratio of the electricity to the magnitude of the space afforded to it be increased, the conductor will be found to undergo an elevation of temperature, which will be greater the greater the quantity of the electricity and the less the space supplied for its passage.

These heat effects are manifested in different degrees in different metals, according to their varying conducting powers. The worst conductors of electricity, such as platinum and iron, suffer much greater changes of temperature by the same charge than the best conductors, such as gold and copper. The charge of electricity, which only elevates the temperature of one conductor, will sometimes render another incandescent, and will vaporize a third.

The better the conducting power of a substance, the lower its electrical resistance, on the other hand the lower its conducting power the more its electrical resistance. A very small percentage of carbon, zinc, iron or other impurity greatly reduces the conducting power of copper, even to one-half.

Iron is frequently used for conductors. This is owing to its comparative cheapness.

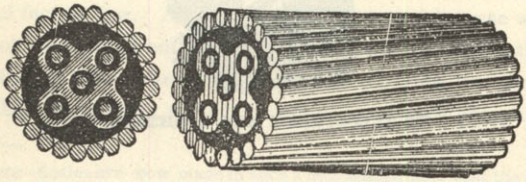
In case of wires, or other conductors, passing through walls, etc., they must be covered with a layer of coating of cotton or silk, wrapped or braided over the wire.

When wires or cables are to be used under water, they must be made impervious, and great care must be used to prevent

the water from penetrating and thus injuring the insolation—the insulating material must possess a good degree of non-conducting power.

It would be a wise plan, and should always be required, that where there is any considerable investment in copper to have submitted by the manufacturer a sample piece of fixed dimensions which can be tested for its conductivity and where it is used for overhead conductors also tested for tensile strength. There are a number of processes used in the production of copper which do not eliminate from the copper those impurities which seriously affect its resistivity. They are not apparent from anything but a test.

FIG. 42.



SUB-MARINE CABLE.

FIG. 43.

TO ILLUSTRATE ARC LIGHTING.

ELECTRICAL MEASUREMENTS.

Electricity has been termed the science of measurements, and

The electrical industry, more than any other, necessitates accurate and varied measurements. Fortunately, the average engineer and electrician may quite readily acquire the knowledge and skill to make all ordinary tests that are necessary, and the cost of needful apparatus is not excessive.

Measurement has been defined as the determination of the value of quantities.

Every system of measurement is based upon some experimental fact or law. An electric current can (1) cause a deposition of metals from their chemical solutions; (2) heat the wire that it flows through; (3) attract (or repel) a parallel neighboring current; (4) accumulate as an electric charge that

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NOTE—Scales are now made of such a nice adjustment that they will weigh anything, to the smallest hair plucked from the eyebrow. They are triumphs of mechanism, and are enclosed in glass cases. Two pieces of paper of equal weight put in the scales, and an autograph written in pencil on either piece will cause the other side to ascend, and the needle which indicates the division of weight even to the ten millionth part of a pound and less will move from its perpendicular. A signature containing nine letters has been weighed and proved to be the fifteen thousand five hundredth part of an ounce, troy.—*Practical Engineer, London, Eng.*

can repel (or attract) a neighboring charge of eletricity; (5) produce in its neighborhood a magnetic field, that is to say, can exert a force upon the pole of a magnet placed near it, as, for example, in galvanometers; the fifth of them is made the basis in the system now adopted by international agreement; and it is the best because, firstly, it connects the electrical units with the magnetic ones, and, secondly, it is closely connected with the mechanical units, enabling the mechanical values of the electrical quantities to be readily computed.

Instruments for measuring currents of electricity are of many styles. As a mysterious and invisible element is dealt with, the measurement is indirect. The effects of currents of various pressures and volumes are what are measured, not the currents themselves.

NOTE.—One of the most sensitive instruments to the effect of the current is the ordinary compass needle. Now if a wire through which an electric current is passing be laid directly above the needle and parallel to it the needle is turned aside from its north and south position. If the current flows in one direction the needle will turn to the right. If the current is from the other direction it will turn to the left.

When the current in the wire is very feeble the needle will be deflected very little from its natural position. If the current be very heavy the needle will be turned aside much more. In order to effect the needle with very small currents the influence must be increased and this is done by winding a hollow, flat coil about a space large enough to contain the needle. This gives many turns of wire above and below the needle and the effect upon the needle is multiplied in proportion to the number of turns.

Upon this principle depends the working of the galvanometer, the voltmeter and ammeter. All are constructed upon the same principle but the voltmeter usually has many turns of very fine wire while the ammeter has but a few turns of very heavy wire.

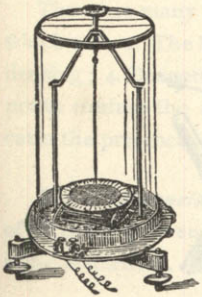
ELECTRICAL MEASUREMENTS.

If water could be neither seen nor felt we should have to determine its volume and height of fall by the effects of the stream upon various sizes of waterwheels, the effect of steam pressure upon a piston, etc.

With the growth of electrical science many specially designed instruments for measurments of electricity have been placed upon the market; almost the first was

The Galvanometer, which is chiefly used to measure battery currents. A galvanometer must fulfil the essential condition that its readings shall really measure the strength of the current in some certain way. It should also be sufficiently sensitive for the currents that are to be measured to affect it. The galvanometer adapted for measuring very small currents (say a current of only one or two millionth parts of an *ampère*) will not be suitable for measuring very strong currents, such as are used in producing an electric light. Moreover, if the current to be measured has already passed through a circuit of great resistance (as, for example, some miles of telegraph wire), a galvanometer

FIG. 44.



THE GALVANOMETER.

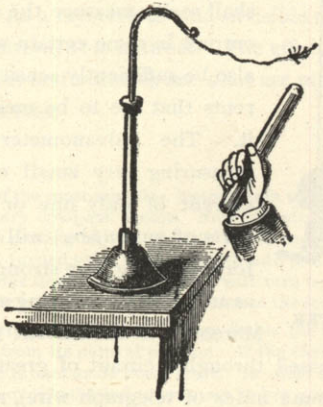
NOTE.—Strong currents must not be passed through very sensitive galvanometers, for, even if they are not spoiled, the deflections of the needle will be too large to give accurate measurements. In such cases the galvanometer is used with a shunt, or coil of wire arranged so that the greater part of the current shall flow through it, and pass the galvanometer by, only a small portion of the current actually traversing the coils of the instrument.

ELECTRICAL MEASUREMENTS.

whose coil is a short one, consisting only of a few turns of wire will be of no use.

The *Galvaniscope* is an instrument used for ascertaining whether a current is flowing or not. It is an indicator of currents where the movement of the needle shows the direction of the current, and indicates whether it is a strong or a weak one. When the value of the readings have been determined by experiment or calculation any galvaniscope becomes a galvanimeter.

FIG. 45.



THE ELECTROSCOPE.

NOTE.—The Henly quadrant electroscope is sometimes employed as an indicator for large charges of electricity. It consists of a pith ball at the end of a light arm fixed on a pivot to an upright. When the whole is electrified the pith ball is repelled from the upright and flies out at an angle indicated on a graduated scale or quadrant behind it. The device shown in Fig. 45 illustrates the same principle of "electric repulsion."

ELECTRICAL MEASUREMENTS.

The Electroscope is an instrument for detecting whether a body is electrified or not and indicating also whether the electrification is positive or not, The earliest electroscope devised consists of a stiff straw balanced lightly upon a sharp point; a thin strip of brass or wood, or even a goose quill, balanced upon a sewing needle, will serve equally well. When an electrified body is held near the electroscope it is attracted and turned round, and will thus indicate the presence of electricity.

There are many forms of the electroscope, notable among which are: 1. The Pith Ball; 2. The Gold Leaf; 3. The Condensing; 4. Bennett's; 5. Bohenberger's. Care must be used not to confuse the idea of the electroscope, which only indicates the presence, with the following:

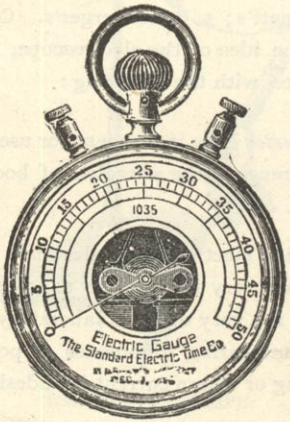
The Electrometer is an instrument for use in measurement of potential difference by the attraction of bodies charged with static electricity.

The "quadrant electrometer" designed by Lord Kelvin is sometimes made very sensitive so as to measure as low as $\frac{1}{1000}$ volt, but it is a very delicate laboratory instrument. It is valuable for measuring differences of potential where no current is flowing or where current is undesirable.

The Mirror Galvanometer.—When a galvanometer of great delicacy is needed, the moving parts must be made very light and small. To watch the movements of a very small needle an *index* of some kind must be used, indeed, in the

tangent galvanometer, it is usual to fasten to the short stout needle a delicate stiff pointer of aluminum. A far better method is to fasten to the needle a very light mirror of silvered glass, by means of which a beam of light can be reflected on to a scale, so that every slightest motion of the needle is magnified and made apparent. The *mirror galvanometers* devised by Sir W. Thomson for signalling through submarine cables, are admirable examples of this class of instrument.

FIG. 46.



THE BATTERY GAUGE.

Fig. 46 represents a form of portable galvanometer, suitable for ordinary testing.

ELECTRICAL MEASUREMENTS.

Measurement of electric pressure and current volume.

The foregoing described instruments belong rather to the experimental and testing departments of electrical science, but the introduction of the dynamo and motor, with their powerful currents have demanded other instruments of greater range and capacity. This has caused the development of instruments for measuring

The Volt.

The Ampere.

The Ohm.

The Volt is the practical unit of measurement of *pressure.*

The Ampere is the practical unit of measurement of *rate of flow.*

The Ohm is the practical unit of measurement *of resistance.*

An Ammeter or ampere meter is a device for measuring the number of amperes which are passing through a current and showing the same by direct reading on a scale.

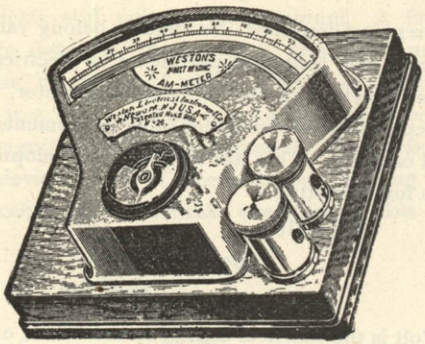
The ammeter is a commercial form of galvanometer in which the deflections (or twistings) of a magnetic needle are valued in amperes.

Ammeters are made in various forms based upon several different principles, among which are

1. Permanent-magnet ammeters.
2. Electro-magnet ammeters.
3. Spring ammeters.
4. Gravity ammeters.

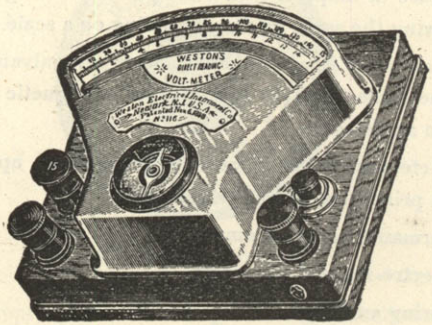
ELECTRICAL MEASUREMENTS.

FIG. 47.



THE AMMETER.

FIG. 48.

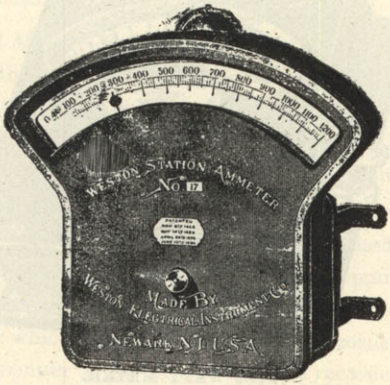


THE VOLT METER.

ELECTRICAL MEASUREMENTS.

When electric motive force of one volt passes through a resistance of one ohm it produces one ampere, hence an ampere is a combination of two things, electric motor force and resistance. An ampere will do a certain amount of work, will decompose a given weight of water, and will deposit .005084 grain of copper per second and in several ways it may be demonstrated what an ampere is. An ampere measurer is just as necessary to all constant current circuits as is a steam guage to a steam plant.

FIG. 49.



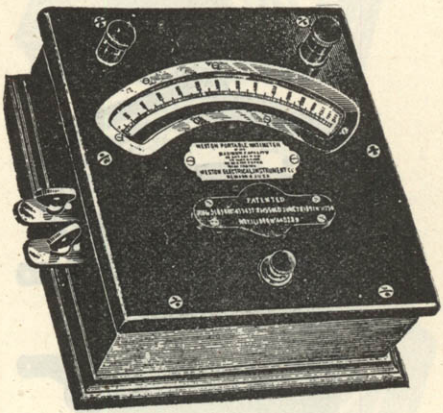
STATION AMMETER.

Some ammeters are designed to be used only for standards of comparison and others are intended and so constructed that they can remain continuously in circuit. Each instrument, if well constructed, has considerable range. See Fig. 47.

ELECTRICAL MEASUREMENTS.

The Voltmeter is shown in Fig, 48. It is different from the ammeter in having high resistance and is connected between the two poles or positive and negative wires. The voltmeter measures electric pressure just as the steam guage measures the pressure of steam. In the illustration two scales are shown, the outside one indicating volts and the inner scale one-twentieth of a volt.

FIG. 50.



THE WATT METER.
(1-5th Actual Size.)

An instrument that will measure accurately from 1 to 100 volts will not give good results for measuring potentials of 1,000 to 5,000 volts. An ammeter that will measure accurately the thousandths of amperes in the current of an induc-

tion coil, will not do at all for measuring 100 or 1,000 amperes. Fig. 47 shows the standard ammeter and Fig. 49 instrument for use to indicate large station output of electricity.

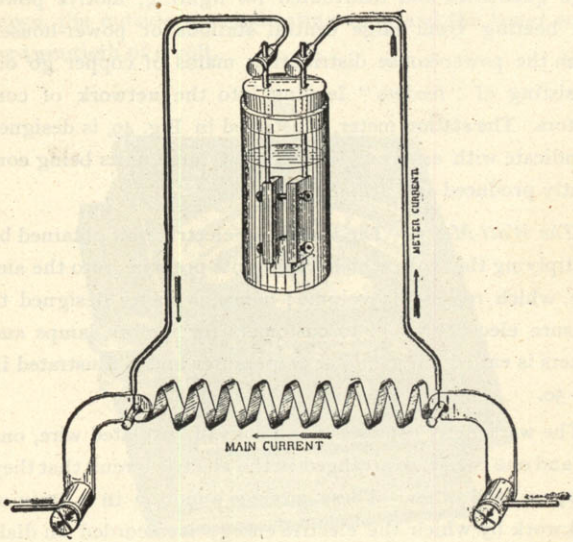
The Station Meter.—Electric energy is now supplied in large quantities and distributed for lighting, motive power and heating from large central stations or power-houses. From the power-house distributing mains of copper go out consisting of "feeders" leading into the network of conductors. The station meter, illustrated in Fig. 49, is designed to indicate with extreme accuracy the large units being constantly produced and utilized.

The Watt Meter.—The watt is an electric unit obtained by multiplying the volt, which represents pressure, into the ampere, which represents volume; hence, a meter designed to measure electricity sold to customers for motors, lamps and heaters is called a watt-meter or measurer and is illustrated in Fig. 50.

The watt-meter consists of two coils of insulated wire, one fine and one coarse, so arranged in the electric circuit that they act upon each other. These produce a motion in a train of clockwork by which the electric energy is recorded on dials in the same manner as gas consumption is recorded in a gas meter. This record is made in watt hours, being 1 volt $\times$ 1 ampere $\times$ 1 hour=one watt hour.

ELECTRICAL MEASUREMENTS.

FIG. 51.



THE EDISON METER.

NOTE.—This is *a chemical meter*, the amount of chemical action being proportioned to the ampere hours.

ELECTRICAL MEASUREMENTS.

The Edison Meter is shown in Fig. 51. A glass bottle contains two zinc plates, immersed in a standardized solution of sulphate of zinc. The electric current enters the bottle from the terminal of one plate, passes through the solution and goes out through the terminal of the other plate. In so doing it disintegrates from the "losing plate" particles of zinc and deposits on the "gaining plate" their exact equivalent. The amonnt thus transferred is in exact proportion to the amount of current passing through the bottle, according to a well-known physical law. The quantity of current shunted through the bottle is a definite proportion of the quantity going directly into the house, "resistances" within the meter fixing the exact proportions. The exactness of this proportion is verified before the meter is placed on the system, and can be checked at any time by electrical tests on the consumer's premises.

Each three wire meter contains two pairs of bottles, one pair on the positive, the other on the negative side of the system. The same amount of current passes through each bottle of the pair and by weighing the "gaining plate" in one bottle and the "losing plate" in the other, a double check is obtained.

NOTE.—After a meter is installed on a customer's premises it is then sealed until the next round of the "meter-wagon." The company's representative unseals the meter, removes the bottles, replacing them by others whose plate-weights have been carefully recorded, and brings the four bottles in a four-part box back to the Meter Department. Each meter has its proper number; each bottle-box has an identifying label which bears the record of the bottle-changing and meter-inspection; and the plates within the bottles are also specifically numbered.

ELECTRICAL RESISTANCE.

Measurements of Resistance.—Unlike the frictional resistance of water in pipes, the frictional resistance of the wire is readily computed and measured, making the discussion of the internal action of the electric system much simpler than one of the hydraulic system would be. In fact, we may measure the resistance power in a certain definite unit.

The resistances of wires and circuits are measured in practice by comparing them with certain standard "resistance coils," sets of which are often employed arranged in "resistance boxes;" the particular instruments employed in making the comparison being of two kinds, namely, the differential galvanometers and the Wheatstone's bridge.

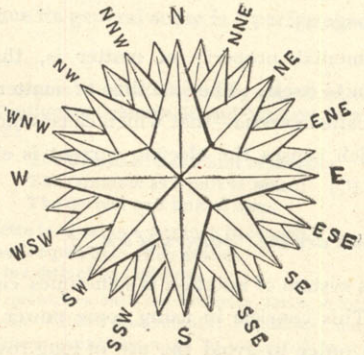
These resistance coils require great accuracy in their measurement, in the insulation of the wire and in the mounting of the coils. The wires must be carefully selected and tested. The insulation must be such as will withstand the highest temperature to which it is subjected without change. Silk thread is extensively used for the insulation. The wire is usually wound on spools or in coils so as to occupy as little room as possible, and are mounted in a box, which protects them from injury and places them in convenient form to be carried.

The ends of the coils are connected to plates or binding posts in the cover. This, also, must be carefully constructed so that the resistance at the point of conract will be as low as possible. A single coil is sometimes placed in an ebony case, or any number, according as the work for which it is to be used seems to require. When a large number is placed in one

box the ends of the wires are usually connected to metal blocks, placed at such a distance apart that a metal plug will make a good connection between any two. The resistance coils being uniform in size, the entire resistance or any part may be used.

The Mariner's Compass.—The practical interest of magnetism (electricity) applied to navigation need not be enlarged upon. The mariner's compass usually consists of a flat circular card, on the under surface of which are secured four to eight light magnetic needles. The card swings in a "compass-box" on a pivot placed at its centre, the box having a pointer corresponding to the direction of the ship's head—the box is supported on gimbols—an arrangement for preserving it horizontal while the ship is pitching and tossing. The card is divided into thirty-two points by a star engraved on it, Fig. 52, and it is by these points the course is steered.

FIG. 52.



THE MARINER'S COMPASS.

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

It is well for the reader to memorize the following questions and answers in the same way that the letters of the alphabet or the multiplication are committed to memory, as more or less of them are used upon every page of printed matter relating to electricity.

QUES. *What is the meaning of the letters E. M. F.?*

ANS. Electro-motive force (abbreviated E. M. F.) is the name given to the force or cause which produces an electric current, see page 45.

The fundamental property of matter is, that it cannot impart motion to itself. The inability of matter to put itself in motion is called *inertia*—that which causes motion is *force* and that which causes the electric current is electro-motive force (E. M. F.)

QUES. *What are the "powers of ten"?*

ANS. This system of notation is sometimes called "Index Notation." This consists in using some power of ten as a multiplier in order to avoid the use of long rows of ciphers.

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

The following examples will show the convenience of the system. The resistance of selenium is about 40,000,000,000, or 4×10^{10} times as great as that of copper; that of *air* is about 10^{26}, or

100,000,000,000,000,000,000,000,000

times as great. The velocity of light is about 30,000,000,000 centimetres per second, or 3×10^{10} times.

QUES. *What is the C. G. S. system of notation?*

ANS. The C. G. S. unit represents the work of a body equal in weight to *one gramme*, through a space equal to *one centimetre* in *one second*. This is the absolute or fundamental unit of electrical work or energy and denominated an *erg*.

QUES. *What is the definition of function?*

ANS. This word is derived from a Latin word meaning to perform—hence its general sense is "performance."

NOTE.—The system of units adopted by almost universal consent is the so-called "Centimetre-Gramme-Second" system, in which the fundamental units are:

The Centimetre as a unit of length;
The Gramme as a unit of mass;
The Second as a unit of time.

The Centimetre is equal to 0.3937 inch in length.
The Gramme is equal to $15.\frac{432}{1000}$ grains.
The Second is 1-60th of one minute.

All physical quantities, such as electricity, force, velocity, etc., can be expressed in terms of these fundamental quantities: length, mass, and time. Each of these quantities must be measured in terms of its own units.

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

QUES. *What is an ohm?*

ANS. An ohm is the practical unit of electric resistance and many researches have been made to determine its working value. For a wire of a certain quality the resistance is in proportion to the length and also in proportion to the cross section or size.

QUES. *What is Ohm's law?*

ANS. The question of relation between volts, amperes and resistance is expressed under one universal law, which is known as Ohm's law, $C=\frac{E}{R}$, in which "C" stands for current, "E" for electro-motive force or volts, and "R" for resistance.

Current in amperes equals pressure in volts divided by resistance in ohms, or again, electro-motive force equals resistance multiplied by current; and again, resistance equals electro-motive force divided by the current; thus it will be seen that these terms are dependent upon each other, and that their relation to each other is expressed by this law.

These are written in three ways:

1. $C. = \frac{E}{R}$
2. $E. = C \times R$, or
3. $R. = \frac{E}{C}$

If one volt will force one ampere of current through a circuit having one ohm resistance it will take five volts to force five amperes through the same circuit. If this resistance should be increased to five ohms it would take five times five

amperes for the proper number of volts to force the amperes through, which would be 25 volts. From this it can be seen that it is very easy to obtain any one of these quantities when we have the other two.

QUES. *What is a volt?*

ANS. The volt represents an electric *pressure* nearly equal to that of a Daniel battery cell described page 55; it is the practical unit of E. M. F. such as may be induced in a conductor which cuts lines of magnetic force at the rate of one hundred millions per second.

QUES. *What is an ampere?*

ANS. The ampere is the practical unit of electric current and represents *a volume* of a current produced by a pressure of one volt flowing through a conductor having a resistance of one ohm.

QUES. *What symbol is used to indicate battery cells joined up in one row, or as they are said to be "in series."*

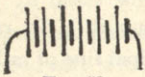
ANS. 

FIG. 53.

By the use of a symbol (see cut) in which a short thick line stands for the zinc and a longer thin line stands for the copper (or carbon). Thus Fig. 53 represents six cells joined in series.

Similar symbols are used for "condensers" in diagrams of electric circuits.

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

QUES. *What is meant by reluctance?*

ANS. The reluctance of a magnetic circuit corresponds with the resistance of an electric circuit.

QUES. *What is the meaning of "coil"?*

ANS. That which is gathered or wound into a ring or circle.

QUES. *What is the definition of "laminated"?*

ANS. It means plated—consisting of plates, layers, or scales laid one over the other.

QUES. *What is the definition of "periphery"?*

ANS. It means the circumference or outside of a circle, ellipsis, or other regular curvilinear figure.

QUES. *What is the definition of the word "potential"?*

ANS. This oft-used word means in its primary sense, power to do work; in this connection it denotes power to do electric work.

QUES. *What is the definition of "shunt"?*

ANS. This is a contraction of "shun it." In railways a turning off to a siding that the principal line of rails may be left free—this idea is transferred to electricity literature.

QUES. *What is the definition of calipration?*

ANS. This word comes from one originally meaning "the diameter of a body" and is kindred to the word "calipers."

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

In electrical literature it means to determine the absolute or relative value of the scale divisions or of the indications of any electrical instrument, such as a galvanometer, watt-meter, etc.

QUES. *What is meant by periodicity?*

ANS. The rate of succession of alternations, or the rate of change in the alternations or pulsations of an electric current.

QUES. *What is staggering?*

ANS. This term is used when one brush is placed slightly in advance of the other brush so as to bridge over a break in the circuit of the armature wires.

QUES. *What is polarity?*

ANS. Polarity is that quality possessed by a mineral when it attracts one pole of a magnetic needle and repels the other.

QUES. *What is meant by the term "inversely"?*

ANS. This means to turn into a contrary direction—a change of order so that the last becomes first.

QUES. *What is meant by permeability?*

ANS. Permeability is the conductivity for magnetic lines of force. In other words, it is a measure of the ease with which magnetism passes through any substance. The permeability of good soft wrought iron is sometimes 3000 times that of air, varying with the quality of the iron.

NOTE.—The magnetic permeability decreases as the magnetization increases. When a piece of iron has been magnetized up to a certain intensity its substance shows a tendency to reach magnetic saturation. In good iron this is reached at about 125,000 lines of force to the square inch of area of cross section.

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

QUES. *What is the air gap?*

ANS. A name given to the part of the magnetic circuit composed of air. Usually the air gap is between the pole pieces and the iron core of the armature. More or less air gap is necessary to provide room for the armature wires and also for mechanical clearance between armature and pole pieces.

QUES. *What is the output of a dynamo?*

ANS. By the *output* of a dynamo is meant the electrical activity of the machine in watts, as measured at its terminals; or, in other words, the output is all the available electrical energy.

QUES. *What is the intake of a dynamo?*

ANS. The *intake* of a dynamo is the mechanical activity it absorbs, measured in watts.

QUES. *What is "torque"?*

ANS. This is the force which produces the motion around a shaft or axis. It is often expressed as the pounds of "pull" excited at the end of a lever arm one foot long. An example is the "pulling" or turning force of an armature of an electric motor, on its shaft.

QUES. *What is the definition of "electrical efficiency"?*

ANS. In a dynamo or generator the relation of total electric energy produced, to the useful, or available electrical energy, thus: if a machine produced but half the work represented by the energy it absorbed, the rest disappearing in

wasteful expenditure—in heating the bearings—in overcoming the resistance of the air, etc., its *efficiency* would be expressed by ½ or "fifty per cent."

QUES. *What is a watt?*

ANS. This is the unit of electric power, or the $\frac{1}{746}$ of a horse power. It expresses the quantity of work per second, done in any electrical resistance. It is the volt-ampere.

QUES. *What is a kilo-watt?*

ANS. The name is given to 1,000 watts. One kilo-watt is slightly more than 1⅓ horse-power. Ex.—A dynamo of 20 units, or a 20 unit machine, is one capable of giving an output of 20 kilo-watts.

QUES. *What is a mil?*

ANS. A mil is one-thousandth part of a lineal inch. It is equal to

.025399 millimeter.
.000083 of a foot.
.001000 of an inch.

A mil is a unit of length.

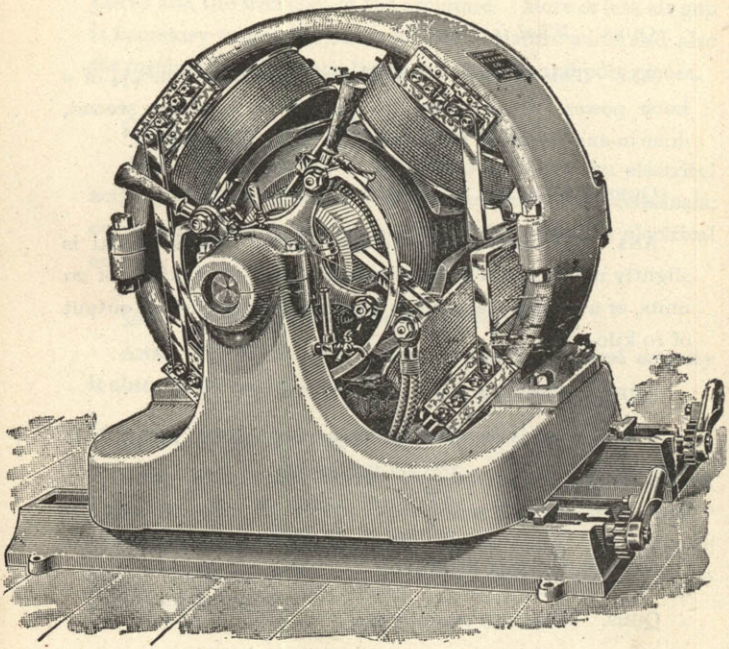
QUES. *What is a circular mil?*

ANS. A unit of area; employed in designating the cross-sectional area of wires and other circular conductors.

It is equal to .78540 of a square mil.

If the diameter of a wire is given in mils the square of its diameter gives its cross-sectional area in circular mils.

FIG. 54.



THE INDIANAPOLIS MACHINE.

THE DYNAMO.

The word dynamo, meaning power, is one transferred from the Greek to the English language, hence the primary meaning of the term signifying the electric generator is the electric power machine.

The word generator, too, is also derived from a word meaning birth-giving, hence also the dynamo is the machine generating or giving birth to electricity.

Again, the dynamo is a machine driven by power, generally steam or water power, and connecting the mechanical energy expended in driving it into electrical energy of the current form.

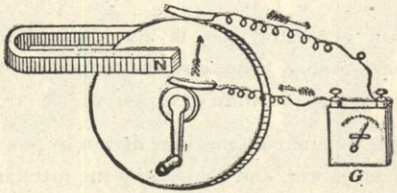
NOTE.—It should be understood that an electric dynamo or battery does not generate electricity, for if it were only the quantity of electricity that is desired, there would be no use for machines, as the earth may be regarded as a vast reservoir of electricity of infinite quantity. But electricity in quantity without pressure is useless, as in the case of air or water, we can get no power without pressure, a flow of currents. As much air or water must flow into the pump or blower at one end as flows out at the other. So it is with the dynamo; for proof that the current is not generated in the machine, we can measure the current flowing out through one wire, and on through the other, it will be found to be precisely the same. As in mechanics a pressure is necessary to produce a current of air, so in electrical phenomena an electromotive force is necessary to produce a current of electricity. A current in either case can not exist without a pressure to produce it.

THE DYNAMO.

Faraday's great discovery was made in the autumn of 1831, and after various experiments he produced his "new electrical machine" shown in Fig. 55. This piece of apparatus is preserved and was shown in perfect action by Prof. S. P. Thompson in a lecture delivered April 11th, 1891, after an interval of sixty years. Its operation is as follows:

"Let a copper disc be hung on a shaft and so balanced as to turn freely. A horse-shoe magnet is so placed that its

FIG. 55.



THE FARRADAY DYNAMO (A. D. 1831.)

inter-polar lines of force traverse the disc from side to side. A copper "brush" is placed so as to touch the shaft, and one to touch the edge of the wheel. A handle serves to rotate the wheel in the magnetic field. Now let the wheel be rotated clockwise, and if the north pole of the magnet is nearest the reader, the result will be to produce a radial current flowing out at the brush on the edge and back, through the brush on the shaft."

In Fig. 56 let D show the dynamos in action and let A B be a long lead with its farther end to earth. Let the other

brush or terminal of the dynamo be also connected to earth. The dynamo when in action is just like a cistern of water at a high level, or a pump; it urges electricity into the lead A B, and at every point *a b c* in the lead there is a certain electric pressure analogous to the water-pressure in the pipe. The electricity flows in the lead between any two points *a* and *b*, in virtue of a difference of electrical pressure between these points; and the flow or quantity per second, or current strength, is determined by two things; this difference of pressure and the resistance of the piece of lead between the points considered. Along the lead there is a regular fall or gradient of pressure represented by the sloping dotted lines in lower part of Fig. 57.

It may thus be seen that the same laws which control the flow of water apply exactly to the electric current.

Dynamos are classified into

1. Unipolar dynamos.

2. Bi-polar (or 2 poles).

3. Multipolar dynamos.

This division is caused by their different construction and is treated under the heading "pole pieces."

The dynamo is used for three principal purposes.

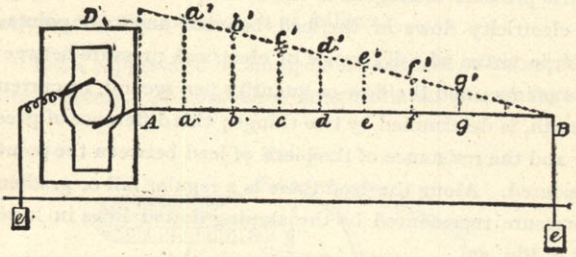
1. Incandesent lighting.

2. Arc lighting.

3. For distribution of power.

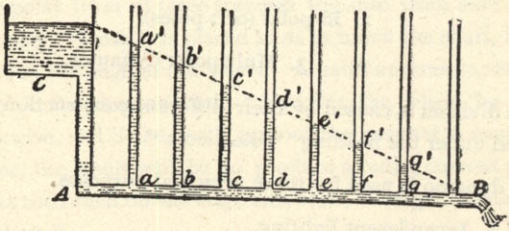
THE DYNAMO.

FIG. 56.



DYNAMO IN ACTION.

FIG. 57.



FLOW OF WATER UNDER PRESSURE, OR HEAD.

THE DYNAMO.

Its various modifications of size and form are designed to meet these, but there is still one other use to which it is put, *i. e.*, for experiments which come outside the limit of this work.

When used for power purposes the machine is called a generator, *i. e.*, it generates electricity to be used through motors.

The dynamo in its very simplest form consists of two main portions: (1) an armature, which in revolving induces electromotive-forces in the copper conductor wound upon it; (2) a field-magnet, that is to say a magnet whose function is to provide a field of magnetic lines, to be cut by the armature conductors as they revolve. In all dynamos, whether for continuous currents or for alternate currents, these two parts can be recognized. In almost all continuous-current machines the field-magnet stands still, and consists of a comparatively simple and massive electromagnet; whilst the armature, which is a more complex structure, is the portion which rotates. In alternate-current machines the field-magnet is usually multipolar, and in the majority of cases is stationary, whilst the armature rotates; nevertheless there are many alternators of recent pattern in which the armature stands still and the field-magnet rotates.

The criterion as to which portion is properly called "field magnet," and which "armature," is not the question of rotation or otherwise. The name of field-magnet is properly given to that part which, whether stationary or revolving, maintains its magnetism steady during the revolution; and the name

armature is properly given to that part which, whether revolving or fixed, has its magnetism changed in a regularly repeated fashion when the machine is in motion.

In the case of continuous current machines there is another feature of first importance, namely, the apparatus for collecting the currents from the revolving armature. This apparatus consists of two essential parts; the commutator (or collector) attached to the armature and revolving with it, and the brushes. The latter, which are conducting contact pieces held pressed against the surface of the rotating commutator, are provided with special brush-holders mounted upon an adjustable frame or rocker.

In the case of alternate-current machines there is no need of a commutator; but, in general, these machines have to be provided with some device for making a sliding connection. For in those forms in which the armature rotates, its coils must be brought into continuous metallic relation with the conductors of the main circuit; and in those forms in which the armature is stationary and no such arrangement is needed at that part, there must still be sliding contacts to maintain the coils of the revolving field-magnet part in continuous metallic connection with the auxiliary exciting circuit. In either case the appropriate device consists of a pair of collecting rings, against each of which a brush presses.

Hence, to summarize, the dynamo-electric generator or the dynamo-electric machine, proper, consists of five principal parts, viz.:

1. The armature or revolving portion.

THE DYNAMO.

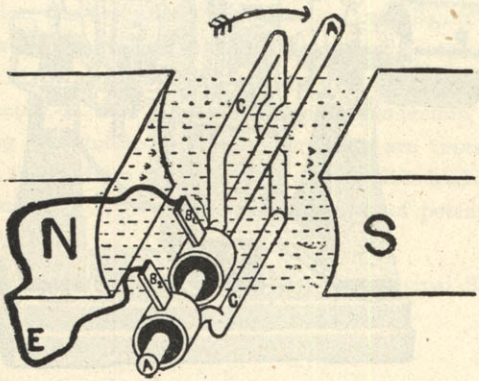
2. The field magnets, which produce the magnetic field in which the armature turns.

3. The pole-pieces.

4. The commutator or collector.

5. The collecting-brushes that rest on the commutator cylinder and take off the current of electricity generated by the machine.

FIG. 58.



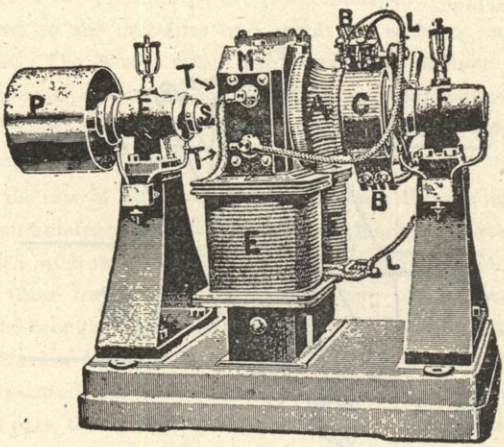
THE SIMPLEST CONCEIVABLE DYNAMO.

The simplest conceivable dynamo is that shown in Fig. 58, consisting of a single loop of wire C C, rotating or turning on spindle A A between the poles of a large magnet N S. The brushes are represented by B B and the electric circuit by the line E. The lines of force are represented by the dotted lines running between the two poles N and S.

THE DYNAMO.

Parts of Dynamo.—The nature and uses of the different parts of a dynamo will be understood by reference to Fig. 59, which represents a complete machine. In this type of dynamo, as in the majority of continuous current dynamos, the magnetic field is stationary whilst the armature revolves in it.

FIG. 59.



A COMPLETE DYNAMO.

The magnetic field in the particular dynamo illustrated is produced by the iron horse-shoe electro magnet M, which is excited by the current flowing in the magnetizing coils E E. The ends or poles of the field magnet M are bored out so as to form a circular chamber within which the armature A rotates. This latter consists of an iron core rigidly fixed to a steel shaft

or spindle S, which revolves in the two bearings F F. Upon one end of the shaft is fixed the driving pulley P. The iron core is overwound with a large number of insulated copper conductors or coils, the ends of which are connected to the circular commutator C. Two stationary metallic brushes, B B, press upon the latter, and convey the current generated in the coils of the armature through the flexible conductors or "leads," L L, to the terminals T T, from whence it is conveyed to the external or working circuit. When the machine is in action, the armature and conductors or coils are caused to rotate within the magnetic field, produced by the electro magnet M, by means of a belt passing over the pulley P. In consequence, E. M. F.s are induced in the conductors, which, on being commutated at the commutator, are transmitted through the medium of the brushes and flexible leads to the two terminals T T, giving rise to a difference of potential between the latter.

In the classification of dynamos the two principal divisions are :

1. Direct current dynamos, and

2. Alternating dynamos, and in each class there are many forms of construction.

The direct current dynamos are again divided into three classes thus :

1. Series wound.

2. Shunt wound.

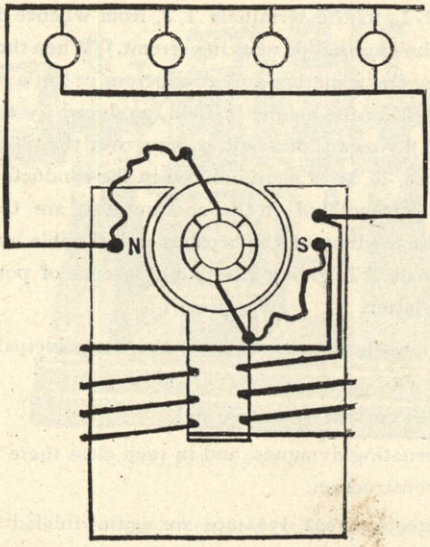
3. Compound wound.

THE DYNAMO.

The manner in which the wiring of the fixed magnets is connected to the armatures gives rise to the foregoing classification.

Series Dynamos.—The manner in which the connections of the series wound dynamo are arranged is shown in Fig. 60.

FIG. 60.

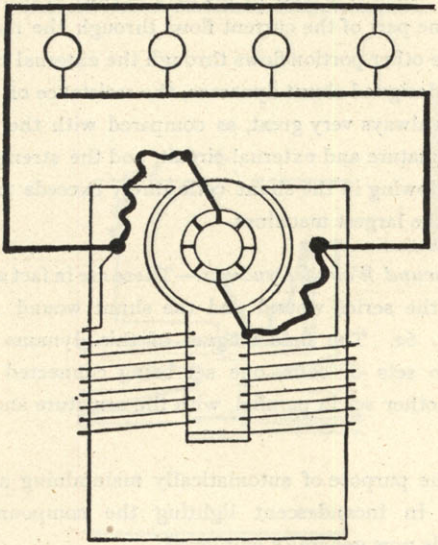


SERIES WOUND DYNAMO.

The coils of the field magnet are wound with a few turns of thick insulated wire, and being joined in series with the armature, the whole of the current generated in the latter passes direct

through them, and thence to the external circuit. The current in passing through the coils of the field magnet energizes the latter, and creates a magnetic field between the two poles N S, in which the armature revolves.

FIG. 61



SHUNT WOUND DYNAMO.

Shunt Wound Dynamos.—The shunt wound dynamo differs from the series wound machine, in that an independent circuit is used for exciting its field magnet. This circuit is composed of a large number of turns of fine insulated copper wire,

which are wound round the field magnet and connected to the brushes, so as to form a shunt or "by pass" to the brushes and external circuit. Fig. 61 shows the connections of the shunt wound dynamo, from which it will be seen that two paths are presented to the current as it leaves the armature, between which it divides in the inverse ratio of the resistance; whilst one part of the current flows through the magnetizing coils, the other portion flows through the external circuit. In all well designed shunt dynamos, the resistance of the shunt circuit is always very great, as compared with the resistance of the armature and external circuit, and the strength of the current flowing in the shunt coils rarely exceeds 12 amperes in even the largest machines.

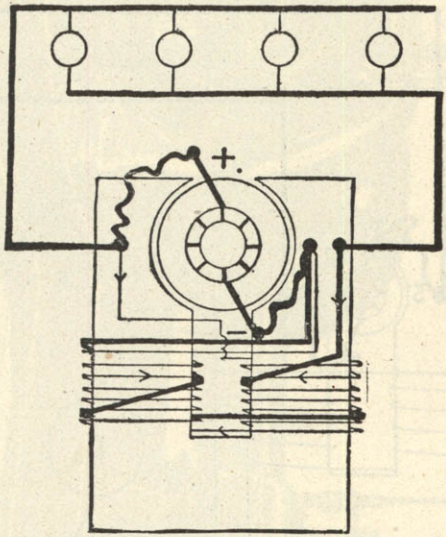
Compound Wound Dynamos.—These are in fact a combination of the series wound and the shunt wound machines. See Fig. 62. The field magnet of this dynamo is wound with two sets of coils, one set being connected in series, and the other set in parallel, with the armature and external circuit.

For the purpose of automatically maintaining a constant pressure in incandescent lighting the compound wound dynamo is now generally employed.

Separately Excited Dynamos.—This type of machine is not so extensively used as the self-exciting type, owing principally to the fact that an independent dynamo or battery is necessary for exciting its field magnet. It finds its chiefest application in the electric transmission of power, and in charging accum-

ulators, and in all cases where a high E. M. F. is required with a varying current. The connections of this dynamo are shown in Fig. 63, where N S are the poles of an electro magnet which is excited by the current generated by the

FIG. 62.



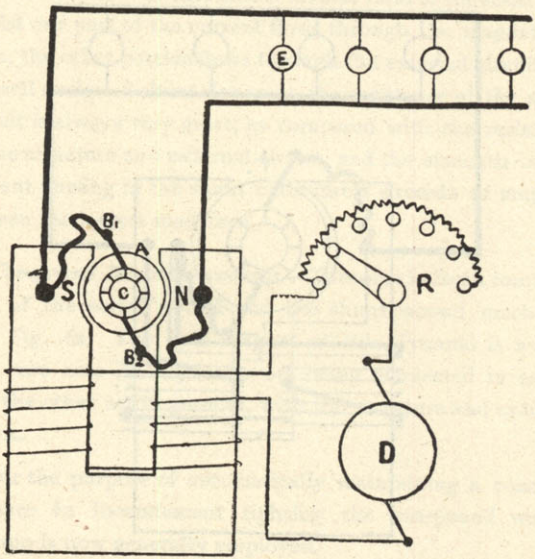
COMPOUND WOUND DYNAMO.

independent dynamo or battery D. The armature A revolves in the space between the two pole pieces, and the two brushes B_1 B_2 press upon the commutator C, and convey the current generated in the armature to the external circuit E. The

THE DYNAMO.

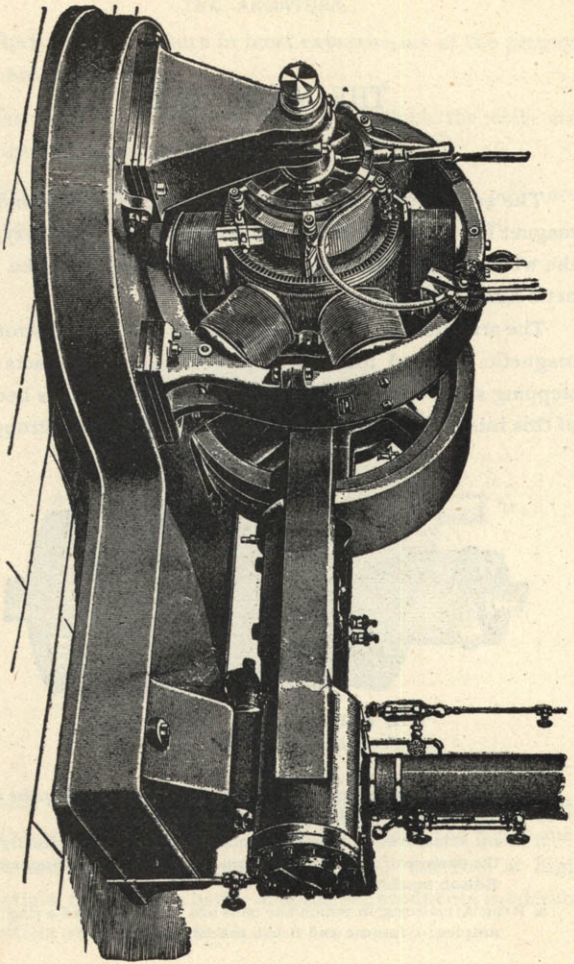
E. M. F. and output of the dynamo is usually regulated by varying the strength of the magnetizing current (produced by the dynamo or battery D) flowing in the coils of the field magnet by means of the hand regulator R.

FIG. 63.



WINDING FOR SEPARATELY EXCITED DYNAMO.

NOTE—In the above illustration, as also Figs. 60, 61, 62, the external circuit is intended to represent a series of lamps in process of receiving the current.



DIRECT CONNECTED STRAIGHT-LINE ENGINE AND GENERAL ELECTRIC DYNAMO.

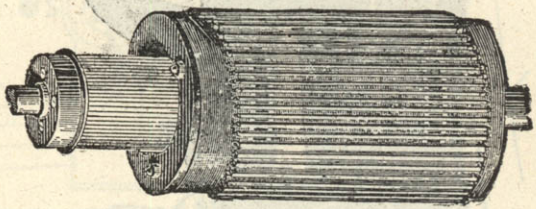
FIG. 64.

THE ARMATURE.

The armature should always be considered as a cylindrical magnet having poles in opposite sides of its periphery, and the whole mass of the armature in what is known as the magnetic flux of the field.

The armature is placed where it will be in the strongest magnetic flux and the iron core of the armature acts as a stepping stone between the poles of the field. It is because of this intermediate mass of iron that the flux is so strong.

FIG. 65.



THE EDISON (BAR) ARMATURE.

NOTE.—There are several ways of arranging the coils upon the armature, and the methods adopted may be classified as follows :—

1. Drum Armatures, in which the coils are wound longitudinally upon the surface of a cylinder or drum. Examples: the Siemens and Edison machines.

2. Ring Armatures, in which the coils are wound around a ring. Examples: Gramme and Brush machines.

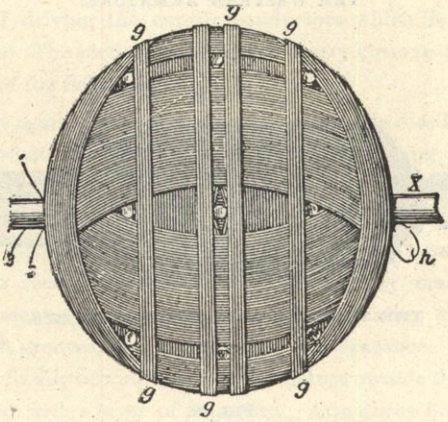
THE ARMATURE.

The types of armature in most extensive use at the present time are the following :—

The Ring or Gramme Armature, in which the coils are arranged upon an iron ring.

The Drum or Siemens Armature, in which the coils are arranged upon the surface of an iron cylinder or drum.

FIG. 66.

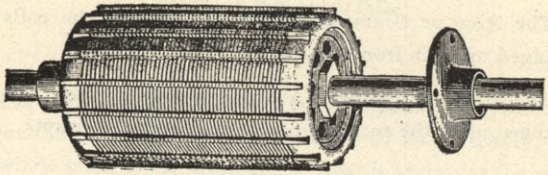


THOMPSON HOUSTON ARMATURE.

Each of these forms of armature has its special advantages, and in a general way it may be said that whilst the ring armature is more suitable for generating small currents at high potentials, the drum is better adapted for producing moderate potentials and large currents.

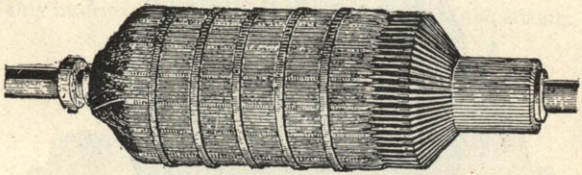
THE ARMATURE.

FIG. 67.



THE WESTERN ARMATURE.

FIG. 68.



THE WESTERN ARMATURE COMPLETE.

FIG. 69.

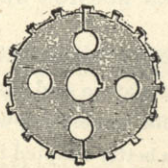


FIG. 69 REPRESENTS THE DISC AS BUILT UP.

THE ARMATURE.

Fig. 66 shows the ring form of armature (Thompson-Houston).

Fig. 65 shows the drum armature (Edison).

Fig. 67 represents the uncompleted form of the drum armature and Fig. 68 the same in order for use.

Fig. 69 represents the toothed core-disk of which drum armatures are largely built up. These have two advantages over smooth disks. (1.) The teeth present an excellent means of driving the copper conductors which lie between them. (2). The teeth may be brought very close to the polar surfaces of the field-magnet.

To set against these real advantages are the disadvantages of somewhat greater labor required in milling out the channels between the teeth of the assembled core; the extra difficulty of insulating the core from the conductors; and the liability of the teeth to set up eddy-currents in the polar faces. The latter can be cured by making the teeth numerous and narrow, also by laminating the polar faces with grooves, and by enlarging the clearance. Or, best of all, by finally serving the entire armature outside the copper conductors with a layer of iron wire. Armatures built up of toothed core-disks have been much used in recent years, particularly for motors. The advantages offered by toothed core-disks are possessed to a still higher degree by core-disks pierced with apertures, for the purpose of ventilation, just within the periphery.

Fig. 70 represents the ring or gramme armature. The arrangement of the lines of force in the magnetic field

between the two poles N and S when the ring is inserted therein, is shown by dotted lines in the figure. If the armature core be rotated in the direction of the arrow, the whole of the conductors, being immovably fixed to the armature,

FIG. 70.

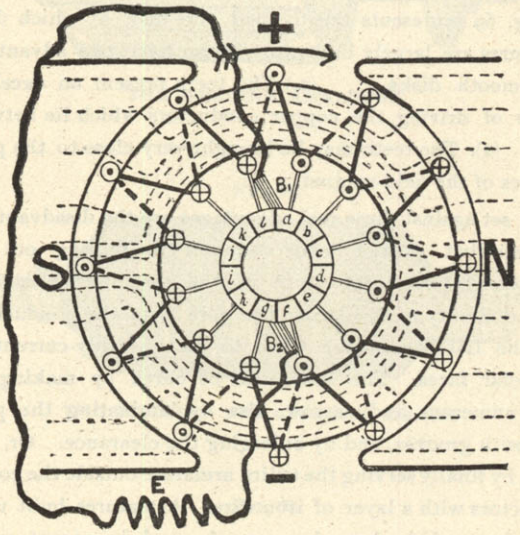


DIAGRAM OF RING ARMATURE.

must necessarily partake of the movement. Owing to this peculiar arrangement a very intense magnetic field is created between the outer surface of the armature core and the pole-faces, while the interior space within the core remains almost entirely free from lines of force.

THE ARMATURE.

A broad distinction may be set up between wire wound armatures and those with built up coils consisting of bars and connectors, or of specially constructed portions that are put together instead of being wound on. These are classified as:

1. Wire wound armatures.
2. Bar armatures.

Wire-wound armatures are usual for outputs below 100 amperes, including all arc-lighting machines. For armatures having outputs exceeding 200 amperes bar-armatures are more frequent, owing to the inflexible nature of wires that are thick enough to carry these currents. The two classes comprise several varieties as under :—

WIRE-WOUND ARMATURES.	BAR ARMATURES.
Single round wire.	Round bars.
Two or more round wires in parallel.	Rectangular bars.
Stranded wire.	Rectangular strips.
Single square wire.	Rectangular bars of compressed stranded wire.
Single rectangular wire.	Special forgings.

The armatures of alternators may be of ring, drum, pole, or disk type ; but in all cases the grouping of the windings is different from that which would be adopted for a direct-current dynamo.

The ring armature is considered the most desirable, because it is not so liable to give out ; and if it does, the cost of repairing is less than for a drum armature, and the time lost on account of the damage is less, as a ring armature may

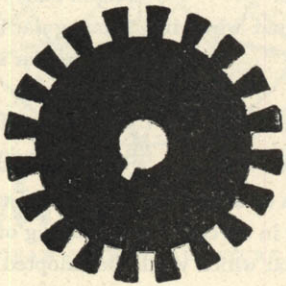
be put in service as soon as the repairs are made; and again when an armature short-circuits, it seldom burns out more than two or three coils. If it is of the ring type the coils can be readily removed and new ones wound in their places, and if the workman is sufficiently skilled he will not have to disconnect the commutator to make the repairs; therefore, the cost of replacing the damaged coils will be small. With a drum armature the case is quite different.

FIG. 76.

KEY WAY.

Armature Cores.—The cores of all practical armatures are now invariably *laminated* or constructed of iron wire ribbons or disks and are frequently constructed with deep channels or

FIG. 72.



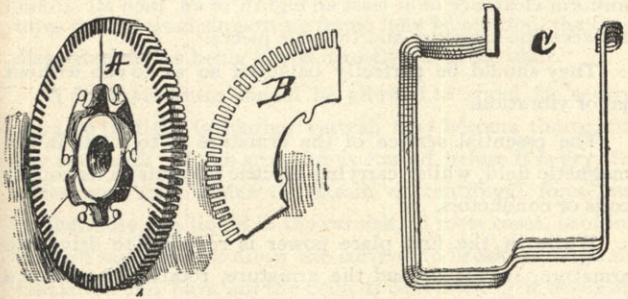
TOOTHED CORES.

grooves in the outer periphery, as shown in Fig. 72, in which the conductors are wound. The projections or teeth in this method of construction present an excellent means of driving

and protecting the conductors, but the difficulty of insulating the latter from the core is increased by their use, and they also have a tendency to produce eddy currents in the pole pieces of the field magnets, causing a heating of the latter. The latter disadvantage can, however, be obviated to a great extent by making the teeth very narrow and numerous.

In most cases notches or keyways are stamped on the inner periphery on the disks as in Fig. 71.

FIG. 73.



LAMINATED CORE.

This core is built up of thin plates of sheet iron of the shape shown at B, Fig. 73. Three of them form a perfect ring with the teeth projecting from the circumference. Upon the inner surface are two hooks which enclose the bolts of the spider. In order to break joints the segments are placed over alternate spaces. This method of building up the core and securing the segments binds the whole firmly together. The

strain is not thrown in the least on the spider, a fact that allows the spider to be made of smaller cross sections.

The winding of the armature is shown at C. It is composed of four wires of the form shown. This winding is carefully insulated before being placed in the slot of the armature core, thus the removal of a coil is an easy matter. The commutator connection is made by means of screws which pass through the connector on the end of the winding.

Points Relating to the Armature.—There should be a uniform clearance of at least an eighth of an inch all around between the armature and the pole pieces.

They should be perfectly balanced so as to run without jar or vibration.

The essential service of the armature is to rotate in the magnetic field, whilst carrying electric currents in its copper coils or conductors.

While in the first place power is required to drive the armature, in the second the armature, rotating, becomes a source of power.

Most makers test their armatures for balance by laying the journals on two parallel metal rails (or "knife-edges") and noting whether the armature will remain in any position without tending to roll. It is well indeed to balance them thus on completing the core ready for winding, and again after winding. If the end core-disks have been made of thick iron, holes can be drilled in these to restore perfect balance; or leaden plugs can be inserted.

THE ARMATURE.

After an armature has been wound the conductors must be secured in their place by a number of external bands, known as binding wires. These must be very strong, to resist centrifugal force and to hold the conductors from being dragged aside; and yet at the same time must occupy very little radial depth, that the clearance between conductors and pole-face may be as narrow as possible. Some makers use hard-drawn brass, others phosphor-bronze, others steel, for binding wires.

Armature cores are usually built up upon an internal frame or skeleton pulley firmly keyed to the shaft. In drum armatures this internal supporting frame may be omitted, the core-disks themselves being keyed directly on to the shaft.

A drum armature should be allowed to stand for several days, so that the insulating varnish may become thoroughly dry and hard. If the armature is started before it is dry, the wires may shift under the strain of centifugal force, and furthermore, the liquid in the varnish, in most cases, is of low enough resistance to allow the current to break through the insulation and burn out the coils, thus rendering it necessary to make the repairs over a second time.

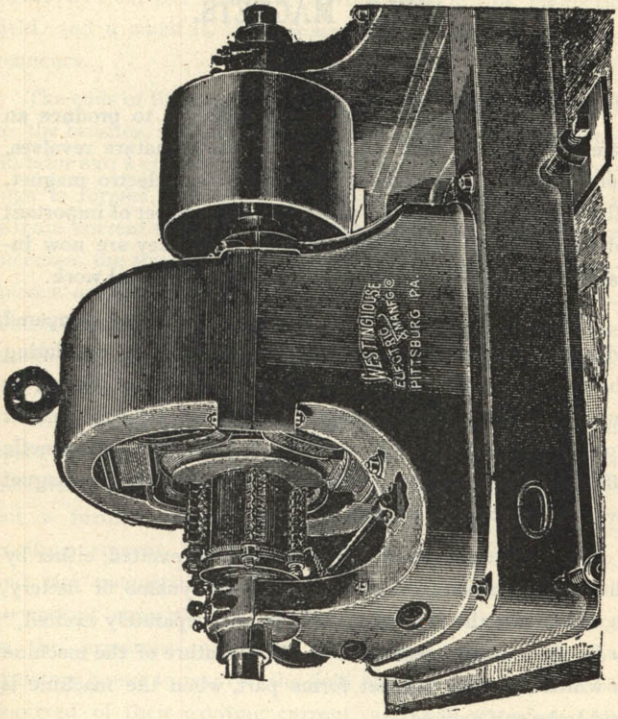
Cores are always laminated, being constructed either of (1) sheet iron *disks*, (2) iron *ribbon*, or (3) iron *wire*. Ribbon is seldom used. For drums and elongated rings, disks stamped out from soft sheet iron are almost universal. The usual thickness is from 40 to 80 mils). They should be of the softest iron. After being stamped out they should be annealed, and the burr at the edges removed. Some makers at this stage assemble them upon the shaft, turn them down

truly in the lathe, then take them apart and remove the burr by grinding lightly on an emery wheel, then remount them. Before being finally mounted on the shaft they must be lightly insulated one from the other. For this purpose it is usual either to cover one face of each core-disk with varnished paper, or to enamel both faces of each core-disk.

It is usual to make the two end core-disks of stronger iron, sometimes as much as ¼-inch thick.

Wire cores were at one time largely in vogue, having been used by Gramme. The soft iron wire, varnished or slightly oxidized on its surface, was wound on a special former, then removed, taped externally, and wound with the copper wire conductors. Wire cores have disadvantages which have largely stopped their use.

FIG. 74.



THE WESTINGHOUSE MACHINE.

FIELD MAGNETS.

The field magnet, the function of which is to produce an intense magnetic field within which the armature revolves, may be either a permanent magnet or an electro magnet. Electro magnets, however, possess such a number of important advantages over permanent magnets, that they are now invariably used in all machines intended for practical work.

The chiefest advantages of the electro magnet, as compared with the permanent magnet, lies in the power of regulating the strength of the magnetic field produced by the former, by suitably adjusting the strength of the magnetizing current flowing through its coils, and also in the greater magnetic effect obtained, weight for weight, from the electro magnet over the permanent magnet.

The field magnets of a dynamo may be excited, either by the current furnished by an independent dynamo or battery, in which case the machine is said to be "separately excited," or by the current generated in the armature of the machine of which the field magnet forms part, when the machine is said to be self-excited.

The latter type of machine depends for its action upon the presence of residual magnetism in its field magnet. Owing to this residual magnetism, a weak magnetic field is always

present between the pole pieces of a field magnet; hence, when the armature is rotated in the armature chamber, its conductors cut the lines of force contained in this magnetic field, and a small E. M. F. is set up in the armature in consequence.

The ends of the magnetizing coils being suitably connected to the brushes, if these latter are in contact with the commutator and a closed circuit through the field magnet windings is formed, this small E. M. F. immediately sends a minute current through the exciting coils; this immediately increases the strength of the magnetic field, and as a consequence an increased E. M. F. is induced in the armature. This results in a stronger current being sent through the exciting coils, and the increase of magnetism which follows results in an increased E. M. F. in the armature.

Thus the process goes on, until eventually, for a given speed of rotation of the armature, the E. M. F. reaches a maximum value, beyond which it will not increase without a further increase in the speed of rotation; the exciting current has then arrived at a constant value, and the magnetization of the machine will remain at a constant strength, and maintain the E. M. F. so long as the armature rotates at its normal speed. If the armature ceases to revolve, the field magnets will of course be deprived of their exciting current, and will therefore lose their magnetism; the iron will, however, retain a sufficient amount of residual magnetism to again start the process when the machine is again started.

FIELD MAGNETS.

Whilst the construction of the armatures of different dynamos may be said to be very much the same, differing in small details only, and being confined to two types, viz., the ring and drum respectively, the construction of the field magnets varies greatly, almost every manufacturer having his own particular form and arrangement. This great variety in the form of the field magnets of different dynamos, is due in a large measure to consideration of economy involved in the manufacture by different makers, and also, to a less extent, to the different conditions under which a machine is required to work. For example, it is sometimes necessary for a machine to give a maximum of output with a minimum of weight, and under such circumstances the field magnet is constructed wholly of wrought-iron, and this necessarily entails an entirely different method of construction and arrangement than if cast-iron were employed.

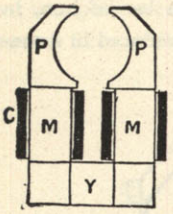
Again, as a rule, the direct coupling of the armature to the engine-shaft involves a different form of field magnet than would be the case if the armature were belt driven.

Owing to difficulties of construction, and other considerations, field magnets are not in practice usually constructed out of a single-piece of iron, but are usually built up of a combination of parts, and composed either wholly of wrought or cast iron, or of a combination of both.

The construction of a typical field magnet is illustrated in Fig. 75, from which it will be seen that it may be divided into five parts, viz.:—the two limbs of cores M M, upon which

FIELD MAGNETS.

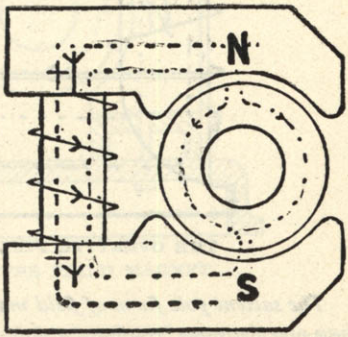
FIG. 75.



TYPICAL FIELD MAGNET.

the exciting coils C are wound; the two end portions P P, called the "pole pieces," which are bored out so as to form the "armature chamber" within which the armature revolves; and the yoke, Y, which serves to connect the two limbs together, and thus complete the magnetic circuit. The permeability of wrought-iron being very much greater than cast-iron, the portions M M of the field magnet, upon which the exciting coils are wound, are frequently constructed of this material; these portions are also usually constructed of a circular section, and thus the amount of wire required for exciting the field magnet is economized to the utmost extent. The pole pieces P P and the yoke Y are in many cases of cast-iron, bolted on to the wrought-iron limbs.

FIG. 76.

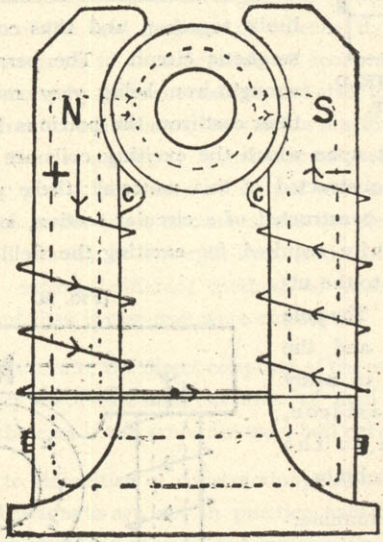


SALIENT POLE FIELD MAGNET.

Although innumerable forms of field magnets have been devised, they can all be arranged into two groups, viz., those in which the poles are "salient," and those in which the poles

are "consequent." A salient pole is the term applied to poles which are produced at the ends of a bar of iron, in distinction to consequent poles, which are produced in a continuous ring of iron.

FIG. 77.

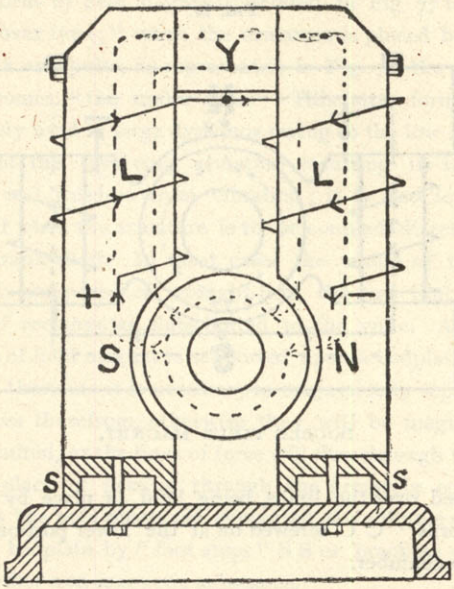


THE OVERTYPE FIELD MAGNET.

The salient pole form of field magnet, being least costly to construct, is most frequently met with in practice. Fig. 76 shows its simplest form; in this arrangement only one magnetizing coil is required, this being wound upon the yoke

which is usually of wrought iron, let into and bolted to the cast iron pole pieces N S. The paths and directions of the lines of force, with the magnetizing current flowing in the

FIG. 78.

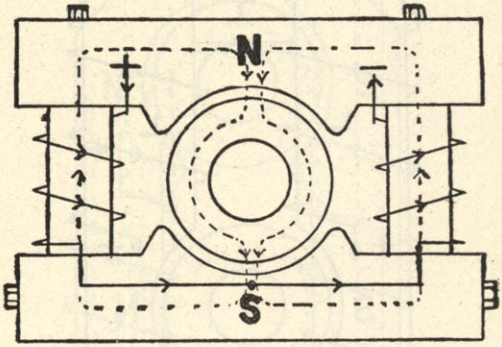


THE UNDERTYPE FIELD MAGNET.

direction shown, is indicated by the dotted arrow heads and lines. Another form of field magnet which is very extensively used, and in which two exciting coils are required, is

shown in Fig. 77. In this type the limbs are usually of wrought-iron, of rectangular section, bolted to the bed place of the machine, which therefore forms the yoke of the magnet. The magnetizing coils are wound upon bobbins, which

FIG. 79.



DOUBLE FIELD MAGNET.

are slipped over the limbs, being held in place by the cast iron "horns" C C screwed on at the lower portion of the armature chamber.

Consequent Pole Field Magnets.—The leading type of consequent pole field magnets are illustrated in Fig. 55. The paths and direction of the lines of force in the field and armature cores are indicated as before by the dotted arrow heads and lines. Fig. 55 may be looked upon as a double

magnet, the exciting coils being wound upon what may be regarded as the yokes of the magnets. The direction of the electric current flowing in the magnetizing coils are such that two similar poles are produced in each pole piece.

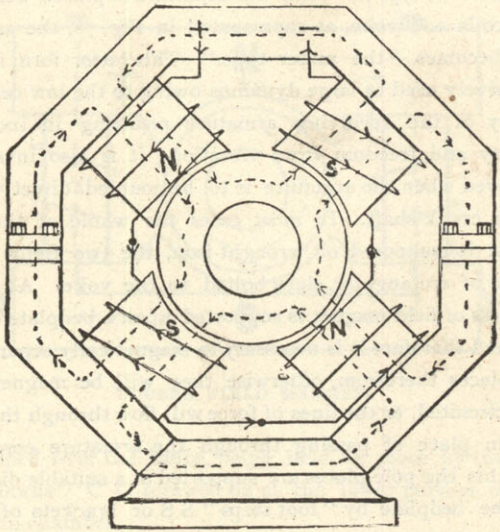
The form of field magnet illustrated in Fig 77 is known as "the over type;" when the armature is placed below the field coils and yoke, as represented in Fig. 78, the arrangement becomes "the under type." This latter form is very extensively used in large dynamos owing to the low centre of gravity of the revolving armature resulting in increased stability and freedom from vibration; it is also invariably employed when the armature is to be coupled direct to the engine crank-shaft. In most cases the whole of the field magnet is composed of wrought-iron, the two limbs being formed of rectangular slabs bolted to the yoke. As a rule, this class of field magnet is supported upon a bedplate of cast iron, and therefore it is necessary to magnetically separate its pole pieces therefrom, otherwise they will be magnetically short circuited, or the lines of force will flow through the bedplate in place of passing through the armature core. To effect this the pole pieces are supported at a suitable distance from the bedplate by "foot steps" S S or brackets of zinc, brass or other non-magnetic substance.

NOTE.—It must always be borne in mind that in all dynamo-electric machines the electro-motive force generated is in proportion to the number of turns of wire in the rotating armature and to the speed of revolution, and the function, or use, of the magnetic field is to produce the proportionate needed lines of force.

FIELD MAGNETS.

Multipolar Field Magnets.—These generally consist of 4, 6, 8 or more poles, arranged in alternate order around the armature. They may be arranged in two classes according as the poles are salient or consequent poles. Fig. 80 represents

FIG. 80.



MULTIPOLAR FIELD MAGNET.

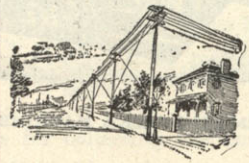
a very commonly used type of multipolar field magnet; it consists of a ring of iron, having four pole pieces projecting inwardly, over which the exciting coils are slipped, the ring forming a common yoke for all the poles. As a rule, it is

made in two portions, bolted together horizontally, so that the upper portion may be lifted off for examination of the armature.

Following the principles, or underlying laws, of the magnetic circuit, the relative values of the very many typical forms of the field magnet may be judged by their approach to these general principles:

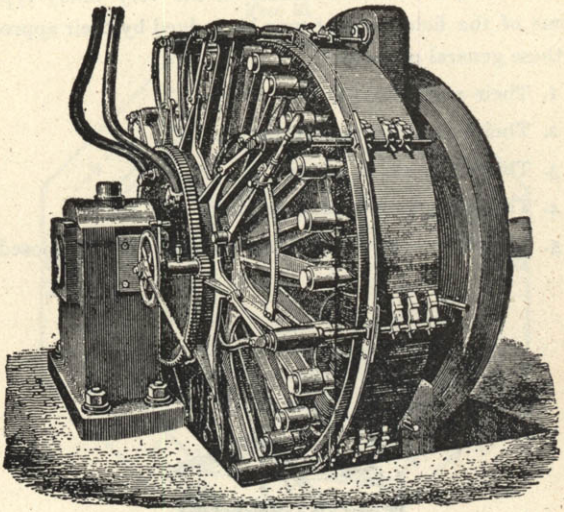
1. Their permeability.
2. Their compactness of form.
3. Their firmness of joints.
4. Their greatness of cross section.
5. The softness of the iron of which they are composed.

FIG. 81.



LINE WORK.

FIG. 82.

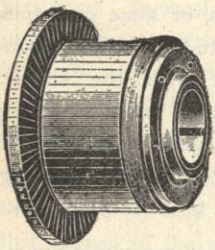


SIEMENS-HALSKE MACHINE.

COMMUTATORS.

These are collectors, or to use the old name, "commuters," of the electric current. Their function or use is to collect the currents produced by the cutting of the lines of force so as cause them all to concur to a desired result.

FIG. 83.



COMMUTATOR.

In general the commutator is formed of alternating sections of conducting and non-conducting material running longwise to the axis upon which it turns. Its place is in the shaft of the machine, so that it rotates therewith. Two brushes, or pieces of conducting material, press upon its surface.

The apparatus for collecting the currents of dynamo-machines may be divided into three types:

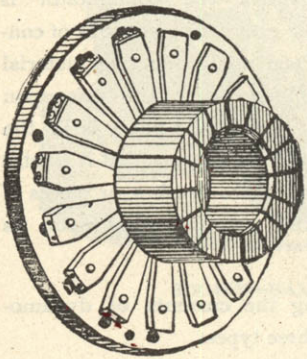
First. Direct-current dynamos with closed-coil armatures, as used for incandescent lighting and other work requiring a constant or nearly constant potential, are furnished with a commutator consisting of a considerable number of parallel

bars secured around an insulating hub, and presenting a cylindrical surface, against which press a pair (or in some cases more than one pair) of brushes or sets of brushes.

Second. Direct-current dynamos of the open-coil type, as used for arc lighting, and giving a constant or nearly constant current, are provided with a commutator consisting of a comparatively small number of segments, each covering a considerable angle, and separated by air-gaps from one another.

Third. Alternators with revolving armatures need a pair of collecting rings of metal, each provided with one or more brushes, or some analogous device to form a sliding connection with the circuit. Alternators with revolving field-magnets need a similar device to convey the exciting current to the moving coils.

FIG. 84.



COMMUTATOR WITH AIR GAP.

Fig. 84 represents a commutator consisting of L-shaped bars bolted to a disk of slate and arranged so that the segments or parts are separated by an air space.

Commutators are made in a great variety of forms. They are used on electric generators, on induction coils and elsewhere for changing the direction of the electric current.

THE COMMUTATOR.

"*Points*" *Relating to the Commutator.*—The number of bars of the commutator depends on the scheme of winding and on the number of sections in which the armature winding is grouped.

Increasing the number of bars diminishes the tendency to spark, and lessens the fluctuations of the current.

An even number of bars is preferable to an odd number; and for ring-wound armatures the cores of which are usually carried on three-armed spiders, it is preferable that the number of bars should be a multiple of three. There are, however, two practical reasons against making the number of bars very great. Increasing the number increases the cost. Again, in large machines having but one turn of the armature winding from each bar of the armature to the next, the number cannot be greatly increased without exceeding the voltage desired.

On the other hand, it is found for small dynamos, that if the number of bars is increased, each bar becomes so thin, that a brush of the proper thickness to collect the current would lap over, or bridge, more than two commutator bars at once.

The bars should be of a length proportionate to the number of amperes that is to be taken off at them. Modern practice varies somewhat, but it may fairly be represented by some such figure as (1.2) 1 1-5th inches for 100 amperes.

The mode of attachment of the bars should be such as to make the greatest amount of length available.

They should also be of considerable thickness to allow them to be turned off occasionally to preserve their roundness.

As for the material most makers use hard drawn copper, made in long lengths of the proper section and cut off to the length required. It is needful to have a good insulation between each bar and its neighbors, and a specially good insulation between the bars and the sleeve or hub around which they are mounted, and also between the bars and the clamping devices that hold them; for the difference of potential is small between neighboring bars, and much larger between the bars and other metal-work. The insulating material must not absorb oil or moisture; hence asbestos and plaster are inadmissible. Vulcanized fibre and paper are not by themselves adequate, though mechanically strong. Mica is the only satisfactory material.

Although the application of the commutator to the coil has the effect of causing the current to flow always in the same direction in the external circuit, it has no effect whatever upon the value of the E. M. F., or the strength of the current, during a complete revolution of the coil. This still remains as before.

The commutator bars are the separated segments or parts upon which the brushes rest.

Alternators have no commutator, but they usually need a pair of sliding contacts to convey the currents to and from the rotating part. The usual device is a pair of contact rings

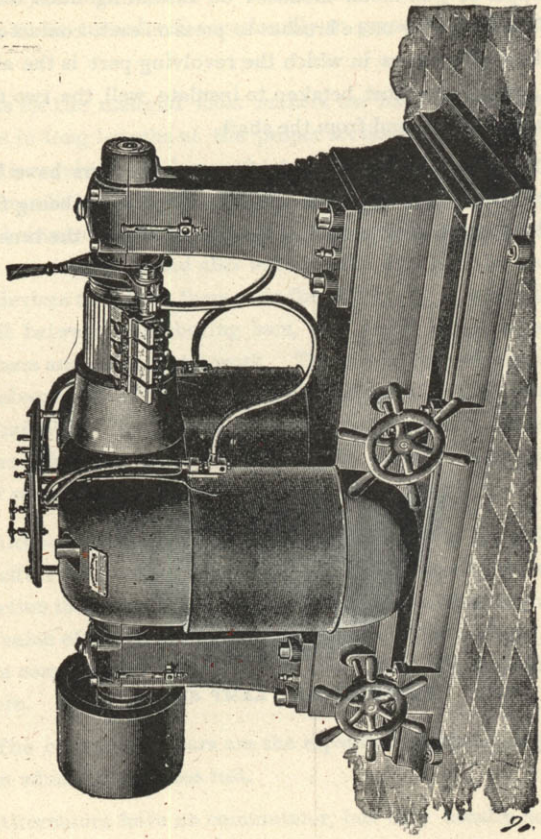
THE COMMUTATOR.

of copper or gun-metal mounted on insulating hubs on the shaft, with one or more brushes to press on each contact-ring. In those alternators in which the revolving part is the armature, great care must betaken to insulate well the two rings from each other, and from the shaft.

Commutators with air-gaps between the bars have been used but the difficulty is to keep the gaps from being filled by the metallic dust produced by the wearing of the brushes.

FIG. 85.

INCANDESCENT LAMP SHADE.

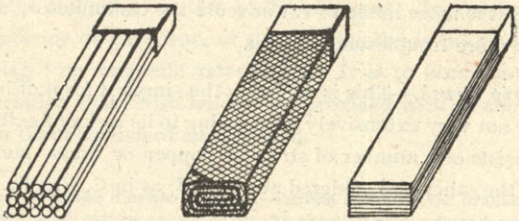


EAU CLAIRE, WIS., MACHINE.

THE BRUSHES.

The brushes bear upon the commutator, and make sliding contact with the armature and working circuits. It is needful that they should have a certain amount of flexibility, in order that they may accommodate themselves to any little inequality which may occur upon the surface of the commutator,

FIG. 87.



and also to avoid cutting or scoring the latter; with these objects, they are usually made of copper or brass gauze, wire, or flexible strip.

Gauze Brushes.—This type of brush is now very extensively used, owing to its great flexibility and soft and yielding nature, resulting in decreased wear of the commutator. It is

made up of a sheet of copper gauze, folded round several times, with the wires running in an oblique direction, so as to form a solid flat strip of from ¼ inch to ½ inch in thickness, as shown at A, Fig. 87, the thickness increasing with the volume of the current to be collected. The object of folding the gauze up with the wires running in an oblique direction is to prevent the ends of the brushes fraying or threading out, which would be the case if the gauze were folded up in any other manner.

Wire Brushes.—This brush (B, Fig. 87) which was much used previous to the invention of the gauze brush, is made up of a bundle of brass or copper wires, laid side by side and soldered together at one end; being harder than the gauze brush, it is more liable to cut or score the commutator, and it is also more troublesome to trim.

Strip Brush.—This is probably the simplest form of brush, but is not very extensively used owing to its lack of flexibility. It consists of a number of strips of copper or brass, laid one upon the other and soldered at one end, as in C, Fig. 87.

Carbon Brushes.—When metallic brushes are used upon the commutators of high tension machines, they frequently give rise to excessive sparking, and also heating of the armature, the metallic dust given off appearing to lodge between the segments of the commutator, thus partially short circuiting the armature. To obviate this, carbon brushes are frequently used on such dynamos, this substance being found very effectual in the prevention of sparking. The brushes

are usually in the form of oblong blocks placed "butt" end on the commutator, and fed forward as they wear away by means of a spring holder.

Wheel Brushes have been employed among the many devices for collecting the current. These consist of small wheels, or disks, bearing against and rotating on the surface of the commutator.

Lead of the Brushes is the dispacement or lead in advance of, or beyond the position at right angles to the line connecting the poles of the field magnet. In a motor the brushes are set back of the right angle or are given a negative lead.

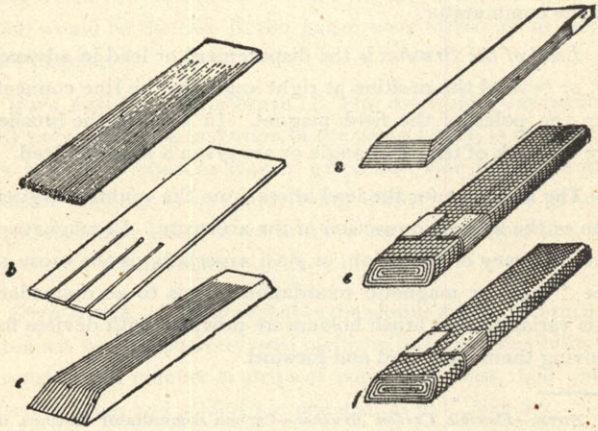
The necessity for the lead arises from the counter magnetism or the magnetic reaction of the armature. In magnetism the tendency of hard iron, or steel especially, is the cause of the "lag" or magnetic retardation. It is to accommodate this variation that brush holders are provided with devices for moving them backward and forward.

NOTE.—*Flexible Carbon Brushes.*—Carbon commutator brushes, as commonly used, consist of one or two blocks of carbon, pressed against the commutator by a spring to maintain the contact. In the case of street railway motors, subject to violent oscillations, the carbons are often jolted away from the commutator, thus causing sparks and burning of the commutator. In order to dispense altogether with springs and at the same time to maintain the pressure constant, Professor Geo. Forbes of London, has devised a brush of flexible carbon, carbonized cloth, compressed into a metal case open at the side, facing the commutator, the case serving both as a holder for the flexible carbon, and also as a terminal for the circuit; owing to its flexibility, it maintains contact with the commutator at an infinite number of points. By this means it is asserted a much better contact is maintained, which is not broken, or even varied, by the jolting on a railroad car.

THE BRUSHES.

In all well-designed dynamos not less than two brushes are used on each side of the commutator; this allows of either brush being removed, and examined and trimmed, while the machine is running. It also allows of the brushes being ad-

FIG. 88.



VARIOUS KINDS OF BRUSHES.

justed upon the commutator independently of each other, any uneven wear of the commutator being thus prevented, and better contact made.

Brush Holders.—In order to secure sparkless collection of the current, and to prevent undue wear of the commutator, it is needful that the pressure of the brushes upon the latter

should be capable of being adjusted to meet requirements; it is also needful that they should be capable of being fed forward as required and that they be furnisued with a movement to permit of the brushes being raised from contact with the commutator when necessary.

Brush Rockers.—As previously mentioned, when a dynamo is working, the neutral points, or the points upon the commutator where sparkless collection of the current can be made, vary in position as the load upon the dynamos varies, moving round in the direction of rotation as the load increases, and *vice versa*. It is necessary, therefore, in order to avoid sparking, to shift the brushes bodily upon the commutator from time to time, without in any way altering the adjustments of the brush-holder springs or breaking the working circuit. To enable this to be effected the brnshes with their holders are, in ordinary bi-polar dynamos, usually fixed upon a "rocker" or "yoke."

Points relating to Brushes.—The brushes must be held firmly, and joined with a good metallic contact to their circuit.

Brush-holders must permit brushes to be withdrawn or fed forward as required.

Brushes must be held to make contact at proper angle to the surface of the commutator.

Brushes must bear with proper pressure upon the commutator; if too light, they will jump and spark; if too heavy, they will cut the commutator into ruts.

THE BRUSHES.

Brush-holders must permit brushes to be raised from contact.

They must also permit, by a proper mechanical catch, of the brushes being held raised out of contact.

Insulated handles should be provided for all dynamos working above 100 volts, so that the brushes may be raised and adjusted without risk of shocks.

The insulation of the brush, or of brush and brush-holder together, must be very thorough.

Each maker has his own particular arrangement for giving these essential motions to the brushes and they are best illustrated in the various "cuts" of dynamos and motors to be found on other pages.

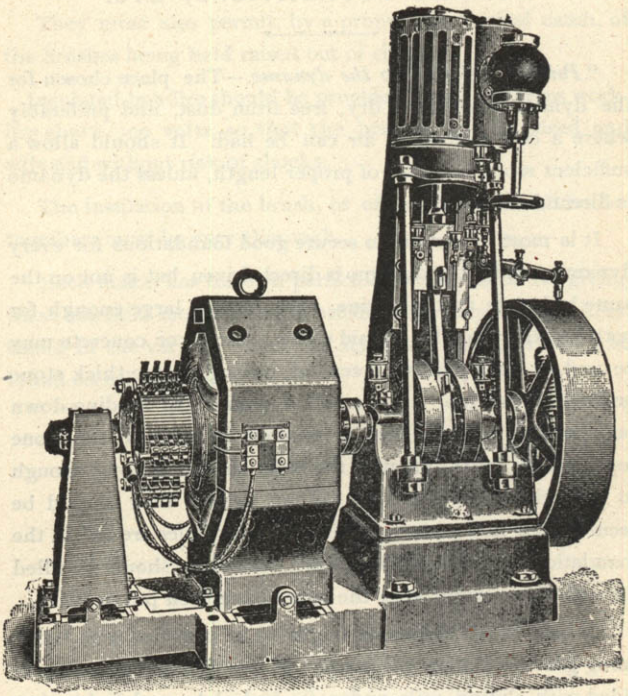
DYNAMO FOUNDATIONS, ETC.

"Points" relating to the dynamo.—The place chosen for the dynamo should be dry, free from dust, and preferably where a cool current of air can be had. It should allow a sufficient room for a belt of proper length, unless the dynamo is direct-driven.

It is most important to secure good foundations for every dynamo; and if the dynamo is direct-driven, but is not on the same bed-plate as the engine, a foundation large enough for both together should be laid down. Stone or concrete may be used, or brick built with cement, having a large thick stone bedded at the top. For small dynamos the holding-down bolts may be set with lead or sulphur in holes in the stone top; but for large dynamos the bolts should be long enough to pass right down to the bottom, where they should be secured into iron plates built in. If long holes are left in the foundations for the holding-down bolts they should be filled in with thin cement after the latter have been put in place.

All belt-driven dynamos ought to be provided with tightening gear to take up the slack. If the dynamo is not provided with sliding rails under its bed-plate and tightening screws, the less desirable method of employing a tenting pulley, may be used. In any case the bed for dynamo must be quite level, and the shaft set properly parallel with the driving pulley.

FIG. 89.



WINDSOR (CONN.) MACHINE.

CARE AND MANAGEMENT OF THE DYNAMO.

When the machine has been securely fixed, and previous to the first starting, the whole of the machine should be carefully examined to see that all parts are in good order, and have not been damaged. The field magnet circuit should first be inspected to see that none of the wires or connections have been broken or are loose, and that the coils are correctly coupled up. The caps of the bearings should next be taken off, and these and the journals carefully cleaned from all grit and dirt. They should then be oiled, and the caps replaced and screwed up with the hand only. The gaps between the outer surface of the armature and the polar faces should be examined in order to ascertain whether any foreign body, such as a small screw or nail has lodged therein. If such is the case, it should be carefully removed with a bit of wire.

The guard plates protecting the armature windings should also be removed, and the windings carefully inspected by slowly rotating the armature, to see that they are not damaged, and that the insulation is perfect. The armature should then be finally rotated by hand to see that it revolves freely, and that the bearings are securely fixed.

CARE AND MANAGEMENT OF THE DYNAMO.

The commutator and brushes should next receive attention—the commutator, to see that it is not damaged in any way through one or more of the segments being knocked in, or the lugs being forced into contract with one another; and the brush-holders and brushes, to see that the latter are clean and make good contact with the brush-holders or flexible leads, and the former to see that they work freely on the spindle, and that the hold-off catches work properly.

In the subsequent working of the dynamo it will of course not be necessary to follow the whole of these proceedings every time the machine is started, as it is extremely unlikely that the machine will be damaged from external causes whilst working without the attendant being aware of the fact. Having ascertained that the machine is not injured in any way, and that the armature revolves freely, the adjustment of the brushes should next be proceeded with.

Attention to Brushes.—The adjustment of the brushes upon the commutator requires careful attention if sparking is to be avoided. The points upon the commutator at which the tips of the brushes, carried by opposite arms of the rocker, bear upon the commutator, should be, in bi-polar dynamos, at opposite extremities of a diameter. In multipolar dynamos the positions vary with the number of poles and the nature of the armature winding. In order to facilitate the correct setting of the brushes upon the commutator, *setting* marks are usually cut in the collar of the commutator next to the bearing.

CARE AND MANAGEMENT OF THE DYNAMO.

In bi-polar dynamos, these setting marks divide the circumference of the commutator into equal parts. In adjusting the brushes, the tips of all the brushes carried by one arm of the rocker are set in correct line with the commutator segment marked out by one setting mark, and the tips of the brushes carried by the other arm or arms are set in correct line with the segments marked out by the other mark or marks.

If one or more brushes in a set are out of line with their setting mark, it will be necessary to adjust the brushes up to this mark by pushing them out or drawing them back, as may be required, afterwards clamping them in position. When adjusting the brushes the armature should always be rotated, so that the setting marks are horizontal. The rocker can then be rotated into position, and the tips of both sets of brushes conveniently adjusted to their marks. In those brush-holders provided with an index or pointer for adjusting the brushes the setting marks upon the commutator are absent, length of the pointer being so proportioned that when the tips of the brushes are in line with the extreme tips of the pointers, the brushes bear upon the correct positions on the commutator.

Having adjusted the brushes to their correct positions upon the commutator, their tips or rubbing ends should next be examined, whilst in position, to see that they bed accurately on the surface of the commutator. In many instances it will be found that this is not the case, the brushes sometimes

bearing upon the point or toe, and sometimes upon the heel, so that they do not make contact with the commutator throughout their entire thickness and width. The angle of the rubbing ends will therefore need to be altered by filing to make them lie flat.

When the brushes do not bed properly upon the commutator, and filing has to be resorted to in order to alter the angle of the brush tips or ends, it will be found necessary to fix the brush in a holder or filing clamp, in order that the correct angle may be conveniently obtained. This, as a rule, is supplied with the machine, and consists of two pieces of metal, both shaped at one end to the correct angle (usually 45°), to which the brushes must be filed. One of the pieces of metal (the back part) has a groove sufficiently large to accommodate the brush, which is clamped in position by the other piece of metal and a pinching screw.

If the clamp is not supplied, a convenient substitute can be made out of two pieces of wood about the same width as the brush. One end of each piece of wood is sawn to the correct angle, and the brush is placed between the two. In filing, the brush is fixed in the clamp, with the toe or tip projecting slightly over the edge of the clamp, and the latter being fixed in a vice, the brush is filed by single strokes of a smooth file made outwards, the file being raised from contact with the brush when making the back stroke.

Having ascertained that the brushes are correctly placed and bedded upon the commutator it remains to adjust their

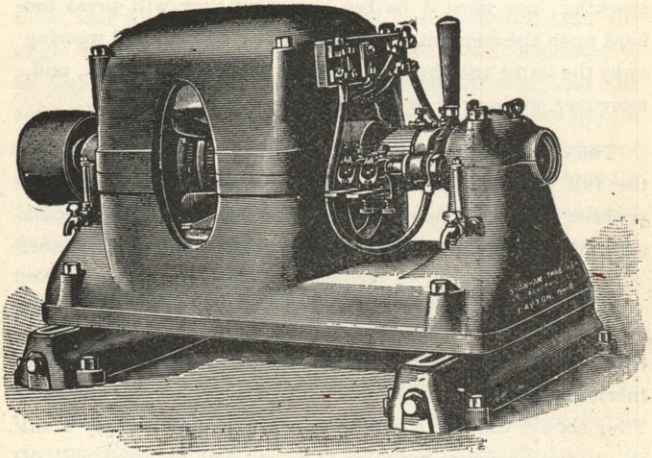
pressure upon the latter. This is effected by regulating the tension of the springs provided for the purpose upon the brush-holders. The tension of the springs should be just sufficient to cause the brushes to make a light yet reliable contact with the commutator. The contact must not be too light, otherwise the brushes will vibrate, and thus cause sparking; nor must it be too heavy, or they will press too hard upon the commutator, grinding and scoring and wearing away the latter and themselves to an undesirable extent, and, moreover, giving rise to great heating and sparking.

The correct pressure is attained when the brushes collect the full strength of current without sparking, while their pressure upon the commutator is just sufficient to overcome any ordinary vibration due to the rotation of the commutator.

Adjusting Lubricators.—As a rule, sight feed lubricators are used in all but the smallest machines. Previous to starting, these should be examined to see that they feed the lubricant properly, and that the oil passages are not clogged. They should then be adjusted to feed an ample supply of oil on to the armature spindle. The amount required will of course depend upon the load and the nature of the oil used, but from 3 to 12 drops per minute of any ordinary heavy hydro carbon oil is generally sufficient for a load varving from 6 to 30 horse-power.

Starting Dynamos.—Having attended to the above preliminaries, and having cleared all keys, spanners, bolts, &c., out of the immediate neighborhood of the machine, and

FIG. 90.



DAYTON (OHIO) MACHINE.

having raised the brushes from contact with the commutator by means of the hold-off catches, the dynamo may be started and allowed to run light.

Whilst thus running, the bearings should be tested from time to time to ascertain if they heat unduly, and an opportunity is also afforded, while the dynamo is thus running, for cleaning the commutator, if this is dirty, with finest emery cloth, afterwards wiping clean with a linen rag. The connections of the machine and external circuits should be verified, and all terminals, &c., cleaned and examined. If found correct, the brushes should be let down on to the commutator, and their tips adjusted by rotating the rocker into the neutral points.

The tips of the brushes carried by one arm of the rocker will, in bi-polar dynamos with vertical field magnets, bear exactly upon the top or highest point of the commutator, while the tips of those carried by the other arm will bear exactly upon the bottom or lowest point of the commutator. In other types of machines, the positions for the brushes will vary according to the class or form of the field magnet and the system of armature winding. If the machine is compound or shunt wound, all switches controlling the external circuits should be opened, as the machine excites best when this is the case; and when the machine is provided with a rheostat or hand regulator and resistance coils, these latter should all be cut out of circuit, or short circuited, until the machine excites, when they can be gradually cut in as the voltage rises.

CARE AND MANAGEMENT OF THE DYNAMO.

When the machine is giving the correct voltage, as indicated by the voltmeter or pilot lamp, the machine may be switched into connection with the external or working circuits. When the machine is series wound, it is absolutely necessary to have the external circuit closed, otherwise a closed circuit will not be formed through the field magnet windings, and the machine will not excite.

Attention to Dynamo after it is started.—When the machine is started and at work, it will need a certain amount of attention to keep it running in a satisfactory and efficient manner. The first point to which attention should be paid is the adjustment of the "lead" of the brushes. If this is neglected, the machine will probably spark badly, and the commutator and brushes will constantly require filing and trimming. The "lead" is the term applied to the slight forward movement which it is found necessary to give to the brushes of most dynamos in order to avoid sparking with an increase of load.

This lead in all good dynamos is very small, and varies with the load and class of machine. The best lead to give to the brushes can in all cases be found by rotating the rocker and brushes in either direction to the right or left of the neutral points, until sparking commences increasing with the movement. The position midway between these two points is the correct position for the brushes, for at this position the least sparking occurs, and it is at this position that the brushes should be fixed by clamping the rocker.

CARE AND MANAGEMENT OF THE DYNAMO.

In series dynamos giving a constant current, such as for arc lamps in series, the brushes require practically no lead. In shunt and compound dynamos the lead varies with the load, and therefore the brushes must be rotated in the direction of rotation of the armature with an increase of load, and in the opposite direction with a decrease of load.

In cases where the dynamos are subjected to a rapidly varying or fluctuating load, it is of course not possible to constantly shift the brushes as the load varies, therefore the brushes should be fixed in the positions where the least sparking occurs at the moment of adjustment. If at any time very violent sparking occurs, which cannot be reduced or suppressed by varying the position of the brushes by rotating the rocker, the machine should be shut down at once, otherwise the commutator and brushes are liable to be destroyed, or the armature burnt up. This especially refers to high tension machines.

As soon as any abnormal sparking is seen at the commutators of such machines, their speed should be at once reduced, and the commutator cleaned up, and the brushes readjusted. Another very important point to be looked to is the lubrication of the machine. The lubricators should be inspected from time to time, to see that they feed the lubricant properly, and that none of the waste oil passages are clogged. The oil should on no account be allowed to get on to the commutator or brushes, or into the windings of the armature, as it is liable to cause sparking at the brushes, and to destroy the insulation of the armature.

CARE AND MANAGEMENT OF THE DYNAMO.

In filling the lubricators, oil cans made of some non-magnetic material such as copper, brass or zinc, should always be used. If iron cans are used, they are liable to be attracted by the field magnets, and thus possibly catch in the armature, and destroy the insulation of the latter. The bearings, and also the field magnet coils, should be tested at intervals, to see that they do not become unduly heated. When testing the temperature of low tension machines, the hand may be used as a guide for judging when the machine is running at a safe temperature.

If the heat of any portion can be easily borne by the naked hand, it may be taken that the temperatnre of the machine is within safe limits. In the case of high tension machines, however, the naked hand cannot be brought with safety into contact with any portion of the machine, and therefore the only way to ascertain if the windings or other electrical parts are at a safe temperature is to apply a thermometer.

It may be taken as a safe rule that no part of a working dynamo should have a temperature of more than 80° Fahr. above that of the surrounding air. Hence, if the temperature of the engine-room is noted before applying the thermometer to the machine, it can at once be seen if the latter is working at a safe temperature. In taking the temperature, the bulb of the thermometer should be wrapped in a woolen rag. The screws and nuts securing the different connections and cables should be examined occasionally, as they frequently work loose through the vibration.

CARE AND MANAGEMENT OF THE DYNAMO.

Attention to Brushes and Commutator.—The brushes and commutator are the most troublesome parts of a dynamo and require most attention. To keep them in a satisfactory working condition, the main thing to be guarded against is the production of sparking at the brushes. If care be taken in the first instance to properly adjust the brushes to their setting marks, and their pressure upon the commutator, and afterwards to attend to the lead as the load varies, so that little or no sparking occurs, and to keep the brushes and commutator free from dirt, grit, &c., and excessive oil, the surface of the commutator will assume a dark burnished appearance, and all wear will practically cease.

Under these circumstances the commutator will run cool, and free from sparking, and will give very little trouble. In order to maintain these conditions it will only be necessary to see that the brushes are properly trimmed and fed forward to their setting marks, as described above, as they wear away, and that the commutator is occasionally polished with the finest emery cloth. If, on the other hand, the pressure of the brushes upon the commutator is too great, or their adjustment is faulty, or the commutator is allowed to get into a dirty condition, sparking will inevitably result, and, if not at once attended to and remedied, the brushes will quickly wear away, and the surface of the commutator will be destroyed.

If this condition of things is allowed to continue, matters will rapidly get worse. In the earlier stages, the surface of the commutator will become roughened or scored, resulting in jumping of the brushes, and increased sparking; in the

later stages, the commutator will become untrue and worn into ruts, and owing to the violent sparking which takes place through this circumstance, the machine will quickly be rendered useless for practical purposes.

When once started, the only way to remedy this condition of things is to repolish the commutator and readjust the brushes, as directed above. If the commutator is merely scored, a smoth file applied while the armature is revolving, with a final polishing with coarse and fine emery cloth, will generally put things into a satisfactory condition. If, however, the commutator is worn into deep ruts, or is untrue, nothing short of putting the armature in the lathe and returning the commutator will make a good job of it.

When carbon brushes are used, a little extra special attention should be given in keeping the commutator perfectly clean, otherwise it is liable to heat up through short circuits, caused by carbon dust lodging between the segments. When carbon brushes are working properly, the fact is indicated by a uniform greyish tinge being imparted to the commutator, with a total absence of heating or sparking of any description.

If the surface of the commutator assumes a mottled or streaky appearance, accompanied by small sparks flashing from segment to segment, it is advisable to slow down the machine and clean up the commutator at once. When either metal or carbon brushes are used, the surface of the commutator is bound in course of time to undergo a certain

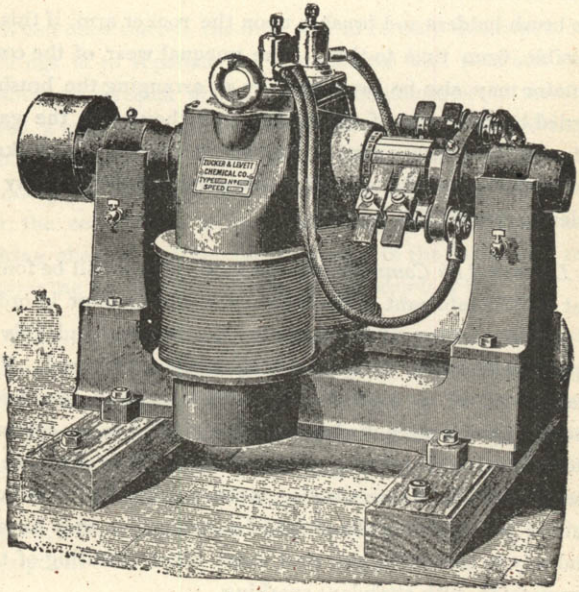
amount of wear, even when the greatest care is taken to reduce sparking.

In order to prevent this wear giving rise to ruts or ridges upon the surfaces of the commutator, it is advisable to shift the brush-holders and brushes upon the rocker arm, if this is possible, from time to time. The unequal wear of the commutator may also be prevented by so arranging the brushes carried by one arm of the rocker that they cover the gaps between the brushes carried by the other arm of the rocker. The armature spindle or shaft is also given a little end play in order to prevent this grooving.

Lubricant on Commutator.—In most cases it will be found that a little lubricant is needed on the commutator in order to prevent cutting of the latter by the brushes, and this is especially the case when hard strip brushes are used. The quantity of oil so used should be very small—a few drops smeared upon a piece of clean rag, and applied to the commutator while running, being quite sufficient. It is advisable to use mineral oil, such as vaseline, or any other hydro-carbon. Animal or vegetable oils should be avoided, as they have a tendency to carbonize, and thus cause short-circuiting of the commutator, with attendant sparking.

Trimming Brushes.—At certain intervals, according to the care taken to reduce sparking, and the length of time the machine runs, the brushes will fray out or wear unevenly, and will therefore need trimming. They should then be removed from the brush-holders, and their contact ends or

Fig. 91.



AMERICAN GIANT DYNAMO.

faces examined. If not truly square, they should be filed or clipped with a pair of shears, the course of treatment differing with the type of brush.

If metal strip brushes, the feathered-out ends should be clipped square with a pair of shears, the ends thoroughly cleaned from any dirt or carbonized oil, and replaced in their holders. Gauze and wire brushes require a little more attention. When their position on the commutator has been well adjusted and looked after, so that little or no sparking has taken place, it will generally be only found necessary to wipe them clean, and clip off the fringed edges and corners with the shears, or a pair of strong scissors. If, however, the machine has been sparking, the faces will be worn or burnt away, and probably fused. If such is the case, they will need to be put in the filing clamp, and filed up square and true, as directed above.

If the contact faces of the brushes are very dirty and covered with coating of carbonized oil, &c., it will be necessary to clean them with benzoline or soda solution before replacing. The handiest way of trimming carbon brushes, or of bedding a complete new set of metal brushes, is to bind a piece of emery cloth or sand paper, face outwards, around the commutator after the current has been shut off, and then mount the carbon or metal brushes in the holders, adjusting the tension of the springs so that the brushes bear with a moderately strong pressure upon the emery cloth or sand paper.

Then let the machine run slowly until the ends of the brushes are ground to the proper form. Care should be taken

however, that the carbon or metal dust given off does not get into the commutator connections or armature windings, or short circuiting will result. If it becomes necessary, through sparking or other causes, to trim the brushes while the machine is working, one brush at a time should be removed from the holders.

The brush to be removed should first be raised carefully from the commutator; then, if excessive sparking or heating occurs, the brush should be let down again, and the tension of the springs of the brushes temporarily increased until the brushes are trimmed. This of course only applies to machines provided with at least two brushes to each set. If only one brush is provided, the machine must be stopped before the brushes can be trimmed.

SHUTTING DOWN DYNAMO.

When shutting down a machine, the load should first be gradually reduced, if possible, by easing down the engine; then, when the machine is supplying little or no current, the main switch should be opened. This reduces the sparking at the switch contacts, and prevents the engine racing.

CARE AND MANAGEMENT OF THE DYNAMO.

When the voltmeter almost indicates zero, the brushes should be raised from contact with the commutator. This prevents the brushes being damaged in the event of the engine making a backward motion, which it often does, particularly when it is a gas-engine. On no account, however, should the brushes be raised from the commutator while the machine is generating any considerable voltage ; for not only is the insulation of the machine liable to be damaged by this proceeding, but in the case of large shunt dynamos an exceedingly violent shock is liable to be administered to the person lifting the brushes.

When the dynamo is at rest, or only revolving slowly, and the brushes are raised from the commutator, the latter should be cleaned up, if this is necessary. In dusty places, such as flour mills, sugar works, cement works, &c., it will probably be necessary to clean off the commutator with benzoline, and finally with finest emery cloth, at the end of every run. In places free from dust. it will only be necessary to wipe the revolving surface perfectly clean, or until it will not soil a white rag, and occasionally to apply a little fine emery cloth before stopping.

When the machine is stopped it should be thoroughly cleaned up. The armature should be dusted with a pretty stiff brush from any adherent copper dust, dirt, &c., and the other portions of the machine should be thoroughly cleaned with linen rags. Waste should not be used, as it is liable to leave threads, fluff, &c., on the projecting parts, terminals

and other parts of the machine, and on the windings of the armature, which is very difficult to remove.

The brushes should be examined, and if necessary trimmed and adjusted, and all terminals, screws, bolts, &c., carefully cleaned and screwed up ready for the next run. The brush-holders should receive special attention, as when dirty they are liable to stick and cause sparking. All dirt and oil should be removed from the springs and contacts, and pivots and other working parts.

It is advisable at stated intervals to entirely remove the brush-holders from the rocker arms, and give them a thorough clean up, by taking them to pieces, and cleaning each part separately with emery cloth and benzoline or soda solution.

Another point to which particular attention should be given is the cleaning of the brush rocker. This being composed wholly of metal, and the two sets of positive and negative brushes being only separated from it by a few thin insulating washers, it follows that if any copper dust given off by the brushes is deposited in the neighborhood of these washers, there is considerable liability for a dead short circuit of the machine to occur, by the dust bridging across the insulation.

These particular parts should therefore be kept scrupulously clean and free from any conducting matter. It is a good plan, when the machine has been thoroughly cleaned up and all connections made secure, to occasionally test the insulation of the different parts. If a record is kept of these tests, any

deterioration of the insulation of the machine can at once be detected, localized and remedied before it has got far enough to cause a breakdown.

As a means of protecting the machine from any moisture, dirt, &c., while standing idle, it is advisable to cover it up with a suitable waterproof cover.

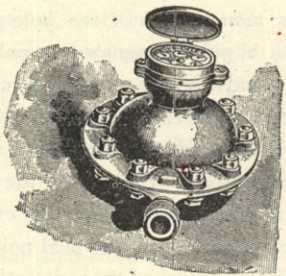
PRACTICAL RULE FOR COUPLING UP FIELD MAGNET COILS.

In coupling up the coils of either salient or consequent pole field magnet coils, assume each of the pole pieces to have a certain polarity (in bi-polar dynamos two poles only, a north and south pole respectively, are required; in multipolar dynamos the poles must be arranged in alternate order around the armature, the number of N and S poles being equal), then apply the rule given on page 81 to each of the coils, and ascertain the direction in which the magnetizing current must flow in each in order to produce the assumed polarity in each of the pole pieces. Having marked these directions on the coils, the coils can be coupled up in either series or parallel according to requirements, so that the current flows in the necessary direction in each.

CARE AND MANAGEMENT OF THE DYNAMO.

Connecting Up Dynamos.—The manner in which the connections of the field magnet coils, and brushes, and terminals, are connected to one another, depends entirely upon the class of dynamo. The field magnet shunt coils of shunt and compound wound dynamos, are invariably arranged in series with one another, and then connected as a shunt to the brushes or terminals of the machine, as represented in Figs. 61 and 62. The series coils of series and compound wound machines, are arranged either in series or in parallel with one another, according to circumstances, and the amount of current given by the machine, and then connected in series to the armature and external circuits upon the principle shown in Figs. 60 and 61.

FIG. 92.



WATER METER FOR POWER STATIONS.

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

QUES. *What is the meaning of the terms "bug" and "bug trap"?*

ANS. The term bug is used to a limited extent to designate any fault or trouble in the connections or working of electric apparatus. The "bug trap" is the arrangement or connection for overcoming the "bug."

These terms are said to have originated in quadruplex telegraphy and been transferred to all electric apparatus.

QUES. *What is the meaning of "synchronous"?*

ANS. It means the occurrence of two events at the same time; caused to act together or occur simultaneously.

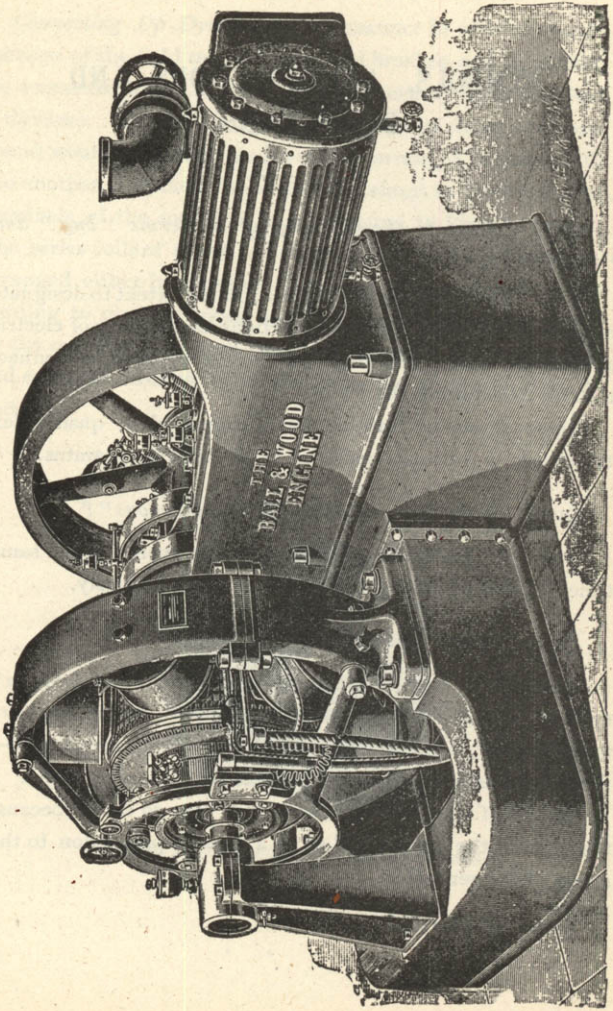
QUES. *Where and how is the word used?*

ANS. It is used in telegraphy—in the "step-by-step" system; with alternating current dynamos, where two are used together, it is necessary that they are "synchronized"—i. e., act together, since otherwise the machine may suffer.

Motors of the "synchronous type," are so called because they run at the same speed or in a certain proportion to the speed of the generator.

NOTE.—See page 114.

FIG. 93.



REGULATING DYNAMOS.

Means of governing the performance of dynamos are needed, not only for keeping the pressure at some constant number of volts or for keeping current at some constant number of amperes, but also for such purposes as to enable the voltage of any one dynamo to be raised in order that it may feed into some distant point of a distributing network.

The output of a dynamo may be regulated or varied by any of the following methods, or by a combination of the same: (1) Variation of speed of armature. (2) Variation of strength of magnetic field. (3) Variation of position of brushes on commutator. (4) Variation of resistance in dynamo circuit. The application of these methods of regulation to the various classes of dynamos is considered in the succeeding paragraphs.

Regulating Separately Excited Dynamos.—The voltage and output of this class of machine is most commonly governed by varying the strength of the magnetizing current flowing through its field magnet coils. When the magnetizing current is furnished by a battery or accumulator, this is

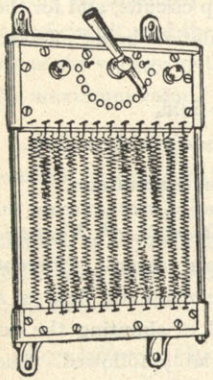
effected either by means of a hand regulator or rheostat inserted in the exciting circuit (as represented in Fig. 94), or by varying the number of cells in circuit, this latter being the most economical plan. In most cases, however, a smaller dynamo is used for the purpose. In this case the strength of the magnetizing current flowing in the coils of the main dynamo may be regulated by either of two methods: (*a*) by means of a hand regulator inserted in the field circuit as before; or (*b*) by varying the voltage of the smaller exciting dynamo. This latter may be effected either by varying the speed of the armature, or by varying the strength of the magnetic field, by regulating the strength of the magnetizing current flowing in the field coils by means of a hand regulator. It is, however, usual to provide the field circuit of each individual dynamo with a hand regulator, so that its pressure may be adjusted independently of the others.

Hand regulators when applied to the regulation of dynamos, consist of multiple contact switches, so arranged that either the resistance of the field magnet circuit may be varied, by inserting or removing resistance in series with the latter, or one or more of the exciting coils may be cut into or out of circuit, or short circuited. When arranged for performing the former operation, the regulator is usually combined with a set of resistance coils.

A combination of this description being illustrated in Fig. 94. It consists of two cast-iron end frames, rigidly connected together by means of two iron rods bolted into the ends of the frames. The two end frames are hollow, and each con-

tain a slate slab, securely fixed in place by means of screws or bolts passing through the slabs, and screwing into the iron frames. The projecting edges of the slate slabs are provided with a number of brass studs or bolts, on to which are fixed the ends of spiral coils of German silver, platinoid, or iron wire. These spiral coils are all joined in series, being formed of a continuous length of wire, which passes up and down between the slate slabs. The connections of the spiral coils to the external circuit are made by means of two terminals, and a number of contacts fixed in the slate slab, in the bottom end frame. The terminal shown on the left of the figure is connected to the extreme left hand spiral coil, the terminal on the right being connected to the lever of the multiple contact switch or regulator, shown at the bottom of the figure. This is composed of twelve contacts, each contact being electrically connected to the bottom junction of a spiral coil. By altering the position of the lever of the regulator the coils can be cut in or out of circuit, and the resistance varied, as may be required. When the regulator is arranged for performing the latter operation, the switch is not combined with a resistance, but the exciting coils of the field magnets are divided up into groups, and the ends are connected to the contacts or terminals in place of the

FIG. 94.



resistance coils, so that by varying the position of the lever each of the exciting coils may be cut into or out of circuit, and the strength of the magnetic field adjusted accordingly.

Regulating Series Dynamos.—The series dynamo is ordinarily used for operating series arc lamp circuits, and for the electric transmission of power, its regulation being effected by any of the following methods :

(1) Variation of strength of magnetic field.

(2) Variatiou of speed of armature.

(3) Variation of position of brushes on commutator.

(1.) *Regulation by Variation of Strength of Magnetic Field.*—Although theoretically there are several different methods of varying the strength of the magnetic field of a series dynamo, in practice, the method of shunting the exciting current in the field coils is invariably followed. The essential principle of this method consists in establishing a shunt of variable resistance across the field coils, so that a portion of the armature current is shunted through the resistance, the remainder being used for exciting the field magnets. The strength of the magnetic field being proportional (within certain limits) to the strength of the magnetizing current flowing in the exciting coils, it follows that the E. M. F. of the machine will vary in proportion to the resistance of the shunt. By reducing the resistance of the latter, a larger proportion of the total current will flow through it, and the strength of the current flowing in the field coils being thus reduced, the voltage of the machine will be reduced also, or

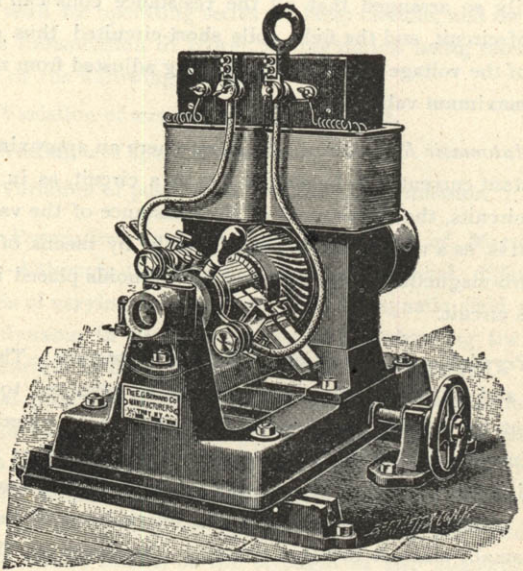
vice versa. The alteration in the resistance of the shunt can be effected by hand, with the aid of a rheostat or hand regulator, similar in principle to that represented in Fig. 96. When used for this purpose, however, the hand regulator is usually so arranged that all the resistance coils can be cut out of circuit, and the field coils short-circuited thus allowing of the voltage of the machine being adjusted from zero to the maximum value.

Automatic Regulation.—In cases where an approximately constant current is to be maintained in a circuit, as in series arc circuits, the adjustment of the resistance of the variable shunt is, as a rule, effected automatically by means of some electro-magnetic device, actuated by solonoids placed in the main circuit.

Regulation by Variation of Speed of Armature.—The voltage and output of series dynamos can be governed to some extent by varying the speed of the armature, by opening or closing the stop-valve of the steam engine, or other motor driving the dynamo. This method of regulation is, however, only applicable in cases where the fluctuations of the load are small, since it involves constant attendance on the engine.

Regulation by Variation of Position of Brushes on Commutator.—In both ring and drum armatures, when rotating in a bi-polar field, there are two points situated at opposite extremities of a diameter of the commutator, at one of which the potential is a maximum, and at the other a mini-

FIG. 95.



THE TROY (N. Y.) MACHINE.

mum, and it is at these points that the brushes must be placed, in order to obtain the greatest difference of pressure.

From the point of maximum potential to the point of minimum potential either way round the commutator, the pressure gradually decreases in value. Hence, if the brushes make contact at points on the commutator other than the neutral points or points of highest and lowest potential, the pressure between the brushes will vary in proportion to their distance from the neutral points, increasing as they approach the neutral points, and decreasing as they recede from them, until when making contact at points situated at about 90° from the neutral points, they will be at nearly the same potential.

From this it follows that by merely rocking the brushes round the commutator, the pressure at the terminals of the machine may be varied and regulated as required. Such a method of regulation cannot, however, be used with advantage in ordinary dynamos, owing to the very destructive sparking which takes place at the brushes when they are moved any considerable distance from the neutral points.

Special dynamos have been designed to meet the special requirements of this method of regulation, and in which the sparking at the brushes is obviated at all loads within the range of the machine, but as these have not come into general use they need not be further considered here.

Regulation of Shunt Dynamos.—In parallel incandescent lighting, it is absolutely necessary to maintain the pressure

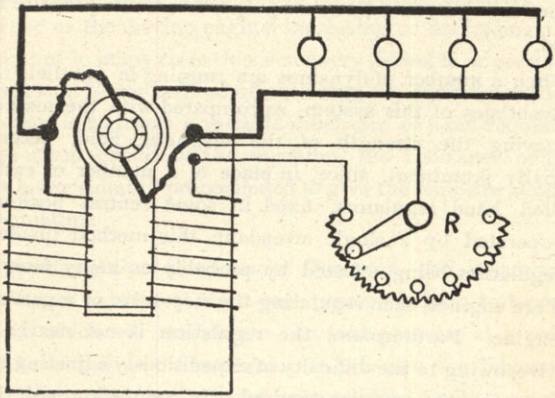
REGULATING DYNAMOS.

at the lamps at a constant value. When the lamps are situated at a considerable distance from the machine, as in town lighting, this necessitates a constantly varying pressure at the machine in order to make up for the fall of pressure in the mains connecting the machine to the lamps, which fall is dependent on the amount of current flowing in the mains. The ease with which this variation of pressure can be effected in the shunt dynamo causes this class of machine to be ordinarily used in central stations for incandescent lighting, the regulation being effected by either of the following methods, or by both in conjunction: (1) Variation of strength of magnetizing current. (2) Variation of speed of armature.

(1.) *Regulation by Variation of Strength of Magnetizing Current.*—This is the only thoroughly efficient method of regulation for a shunt dynamo. The variation in the strength of the magnetizing current is effected by means of a hand regulator or rheostat, similar to that represented in Fig. 94, which is inserted in the shunt circuit of the machine, as shown diagramatically in Fig. 96. In this system of regulation, the resistances of the field magnet shunt windings and of the regulator coils are so proportioned that, when no load is on the dynamo, and all the coils of the regulator are in circuit with the shunt, the machine generates the normal pressure required at the lamps. As more and more lamps are switched on, the voltage at the lamps has a tendency to decrease, and therefore the pressure at the machine must be raised in proportion. This is effected by moving the lever of the regulator (R), so that fewer resistance coils are included

in the shunt circuit; the resistance of the latter being thus decreased, the exciting current and voltage of the machine is increased correspondingly. This method of regulation is common with all in which resistances are included in the circuit, wastes energy to a certain extent, but the quantity so

FIG. 96.



REGULATION FOR A SHUNT-DYNAMO.

wasted is so small in proportion to the whole that it may be considered as of little moment, especially when the advantages of the system are taken into account.

Regulation by Variation of Speed of Armature.—A much less satisfactory method of regulation for shunt dynamos is that of varying the speed of the armature. For small varia-

tions of pressure, the alteration of speed can be readily effected by means of an adjustable governor, the speed of the armature being varied by increasing or diminishing the tension of the governor spring, according to the pressure required at the terminals of the machine. For larger variations, however, the only effective method of regulation is by means of the stop-valve; that is to say, the main stop-valves of the engines are opened or closed in proportion to the pressure required.

When a number of dynamos are running in parallel, the disadvantages of this system, as compared with the method of varying the strength of the magnetic field, become especially prominent, since, in place of a number of easily adjusted hand regulators, fixed in some central position, and operated by a single attendant, this method involves the regulation being effected by probably as many men as there are engines, each regulating the stop-valve of a particular engine. Furthermore, the regulation is not nearly so effective, owing to the difficulty of expeditiously adjusting the valves to give the pressure required. In connection with this particular system of regulation, a special type of voltmeter is generally employed, this being of extraordinary large dimensions, with the index or pointer about 18 inches in length, so that its indications may be seen all over the engine-room.

Regulating Compound Dynamos. — A carefully compounded dynamo will, when run at the speed for which it was designed, regulate itself perfectly, and maintain a constant difference of potential at its terminal under any varia-

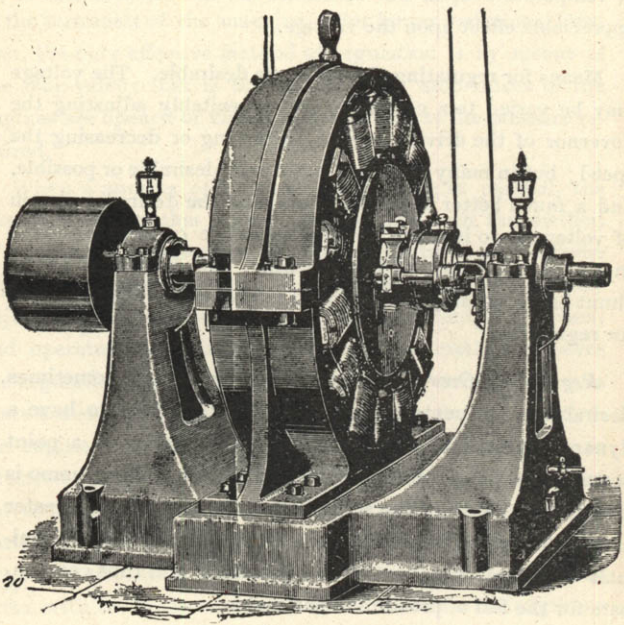
tion of load within its range. In practice, however, it is not always possible to work a dynamo under these exact conditions, and, moreover, in the case of large machines, the effect of temperature upon the resistance of the machine has an appreciable effect upon the voltage.

Means for regulating the latter are desirable. The voltage may be varied to a certain extent by suitably adjusting the governor of the driving engine, increasing or decreasing the speed; but in many cases this is not very desirable or possible, and a much better method of obtaining the desired variation of voltage is to insert a variable resistance or hand regulator in the shunt circuit of the machine, the resistance of the shunt being suitably proportioned to give the requisite margin for regulation.

Regulating Over-Compounded Dynamos.—It is sometimes desirable, as in central light and power stations, to have a dynamo which will maintain a constant pressure at a point some distance from the machine. In this case the dynamo is over-compounded, or the series coils are wound with a greater number of turns, in order to raise the pressure at the terminals of the machine as the load increases, and thus compensate for the fall of pressure in the mains.

As it is well to vary the degree of over-compounding, the series coils of such dynamos are usually so proportioned as to give from 10 per cent. to 20 per cent. of over-compounding, and a strip or ribbon of German silver or copper is arranged as a shunt to the series coils. By suitably including a greater

FIG. 97.



AN ALTERNATOR.

or lesser length of ribbon in the circuit, the resistance of the variable shunt and the amount of current flowing in the series coils can be varied, and the percentage of over-compounding adjusted accordingly.

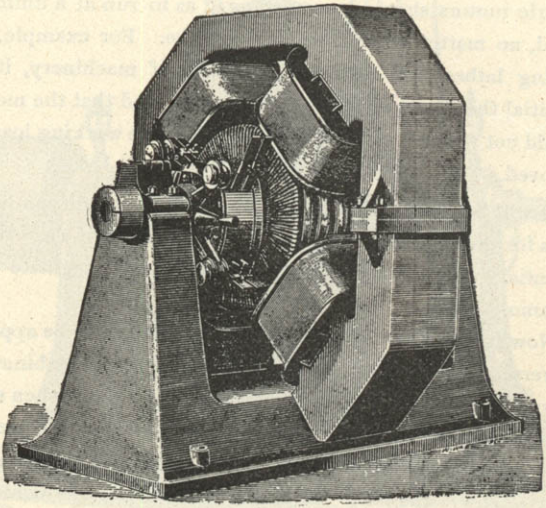
Regulation of Motors.—It is extremely important that electric motors should be so arranged as to run at a uniform speed, no matter what their load may be. For example, in driving lathes, and many other kinds of machinery, it is essential that the speed should be regular, and that the motor should not "race" as soon as the stress of the working load is removed.

It will be evident that the employment of certain combinations for the field magnets, under the condition of a constant potential, when driven at a constant speed, regulate the dynamo.

Now it is not hard to see that this problem may be applied conversely, and that motors may be built with a combination of arrangements for their field-magnets, such that, when supplied with currents under the standard condition of constant potential in the distributing mains, their speed shall be constant whatever the load. It will be evident that the windings must oppose one another—one must tend to demagnetize the field magnet, the other to magnetize.

This effect is based upon the important electrical law that if a current is passed through a dynamo the armature will rotate. In all cases the rotation is in such a direction as to induce in the armature an electro-motive force opposed to that of the driving current.

FIG. 98.



FOUR POLE RING DYNAMO.

COUPLING OF DYNAMOS.

When it is needful to generate a large and variable amount of electrical energy, as is the case in large installations and central generating stations, apart from the question of liability to breakdown, it is neither economical or desirable that the whole of the energy should be furnished from a single dynamo. Since the efficiency of a dynamo is dependent upon its output at any moment, or the load at which it is worked, the efficiency varying from 95 per cent. at full load to 80 per cent. at half load, it is obviously advisable in order to secure the greatest economy in working, to operate any dynamo as far as possible at full load. Under the above circumstances, when the whole of the output is generated by a single dynamo this can evidently not be effected, for the load will naturally fluctuate up and down during the working hours, as the lamps, motors, etc., are switched into and out of circuit; and hence, although the dynamo may be working at full load during a certain portion of the day, at other times it may probably be working below half load, and therefore the efficiency and economy in working in such an arrangement is very low. In order to secure a maximum efficiency, it is usual in such cases to divide up the generating plant into a number of units, varying in size, so that as the load fluctu-

COUPLING OF DYNAMOS.

ates it can either be shifted from one dynamo to another as the exigencies of the case requires; or when the load exceeds the capacity of the largest dynamo in the plant, the output of one can be added to that of another, and thus the dynamos actually at work at any moment can be operated as nearly as possible at full load. As it is necessary to take certain precautions in connecting one dynamo to another, in order that the other dynamos may not be affected by the change, and that they may work satisfactorily together, it is well to consider these in connection with the different types of machines.

Series and Parallel Connections.—Since the output of a dynamo is made up of two factors, viz.: the pressure and the current respectively, it follows that the output of a machine may be increased by increasing either the one or the other, or both at the same time. As, however, the systems of distribution in use at the present time involve the maintenance of either *a constant current* or a *constant pressure* in a circuit, the methods of coupling dynamos together resolve themselves into two kinds, corresponding to the systems of distribution, viz.: *parallel* and *series* connections. In coupling two or more machines in parallel, the pressures of all the machines are kept at a constant value, while the output of the plant is increased in proportion to the current capacities of the machines in circuit. In the series coupling, the current capacity of the plant is kept at a constant value, while the output is increased in proportion to the pressures of the machines in circuit.

COUPLING OF DYNAMOS.

Shunt Dynamos in Series.—The simplest operation in connection with the coupling of dynamos, and the one used

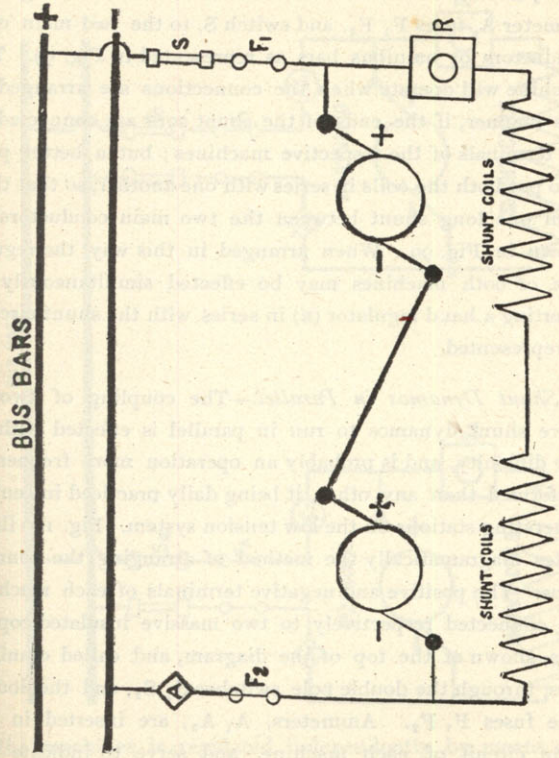


FIG. 98.

probably more frequently in practice than any other, is the coupling of two or more shunt dynamos to run either in

series or in parallel. When connected in series, the positive terminal of one machine is joined to the negative of the other, and the two outer terminals are connected through the ammeter A, fuses F_1 F_2, and switch S, to the two main conconductors or omnibus bars as represented in Fig. 99. The machine will operate when the connections are arranged in this manner, if the ends of the shunt coils are connected to the terminals of the respective machines; but a better plan is to put both the coils in series with one another, so that they form one long shunt between the two main conductors, as shown in Fig. 99. When arranged in this way, the regulation of both machines may be effected simultaneously by inserting a hand regulator (R) in series with the shunt circuit, as represented.

Shunt Dynamos in Parallel.—The coupling of two or more shunt dynamos to run in parallel is effected without any difficulty, and is probably an operation more frequently performed than any other, it being daily practiced in central generating stations on the low tension system. Fig. 100 illustrates diagramatically the method of arranging the connections. The positive and negative terminals of each machine are connected respectively to two massive insulated copper bars, shown at the top of the diagram, and called omnibus bars, through the double pole switches S_1 S_2, and the double pole fuses F, F_2. Ammeters, A_1 A_2, are inserted in the main circuit of each machine, and serve to indicate the amount of current generated by each. An automatic switch or cutout, AC_1 AC_2, is also shown as being included in the

COUPLING OF DYNAMOS.

main circuit of each of the machines, although this appliance is sometimes dispensed with. The pressure of each of

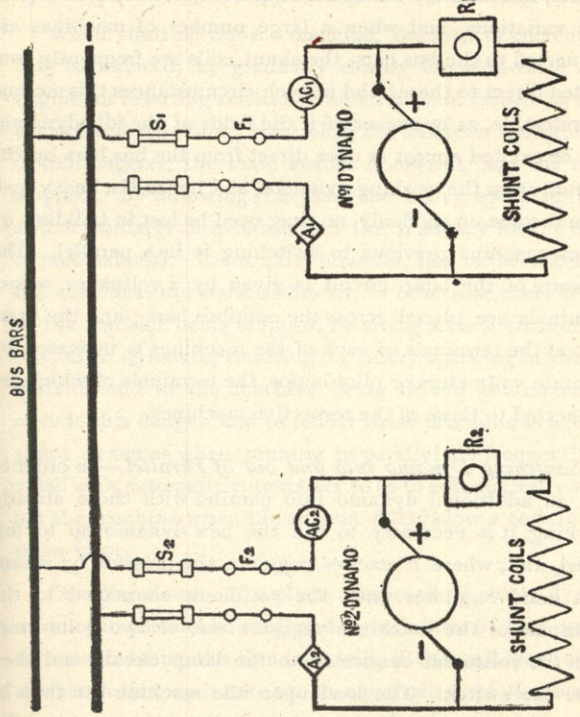


FIG. 100.

the machines is regulated independently by means of the hand regulators R_1 R_2, inserted in series with the shunt circuit.

COUPLING OF DYNAMOS.

The shunt circuits are represented as being connected to the positive and negative terminals of the respective machines, but in many cases, where the load is subjected to sudden variations, and when a large number of machines are connected to the bus bars, the shunt coils are frequently connected direct to these; and in such circumstances this method is preferable, as by means of it the fields of the idle dynamos can be excited almost at once direct from the bus bars by the current from the working dynamos, and hence if a heavy load should come on suddenly, no time need be lost in building up a new machine previous to switching it into parallel. The pressure of the lamp circuit is given by a voltmeter, whose terminals are placed across the omnibus bars; and the pressure at the terminals of each of the machines is indicated by separate voltmeters or pilot lamps, the terminals of which are connected to those of the respective machines.

Switching Dynamo into and out of Parallel.—In order to put an additional dynamo into parallel with those already working, it is necessary to run the new dynamo up to full speed, and, where it excites, regulate the pressure by means of a hand regulator until the voltmeter connected to the terminals of the machines registers one or two volts more than the voltmeter connected to the lamp circuit, and then close the switch. The load upon the machine can then be adjusted to correspond with that upon the other machines by means of the hand regulator. In this class of machine there is little or no danger of overloading an armature when connecting it to the bus bars, and therefore the pressure need not

be adjusted with very great accuracy; in fact, it is common practice in central stations to judge of the voltage of the new dynamo merely by the appearance of its pilot lamp.

When shutting down a machine, the load or current must first be reduced, by gradually closing the stop-valve of the engine, or inserting resistance into the shunt circuit by means of the hand regulator; then when the ammeter indicates nine or ten amperes, the main switch is opened, and the engine stopped. By following this plan, the heavy sparking at the switch contacts is avoided, and the tendency for the engine to race reduced. Great care, however, has to be taken that the current is not reduced too far, or otherwise there is a risk of the machine being stopped, receiving a back current from the other dynamos, resulting in heavy sparking at the commutator, and in the machine being driven as a motor. To obviate this danger, and to render these precautions needless, shunt dynamos when running in parallel are frequently provided with automatic cutouts, set so as to automatically switch out the machine when the current falls below a certain minimum value.

Dividing Load.—If a plant composed of shunt dynamos running in parallel be subjected to variations of load, gradual or instantaneous, the dynamos will, if they all have similar characteristics, each take up an equal share of the load; if, however, as is sometimes the case, the characteristics of the dynamos are dissimilar, the load will not be shared equally; the dynamos with the most drooping characteristics taking less than their share with an increase of load, and more than

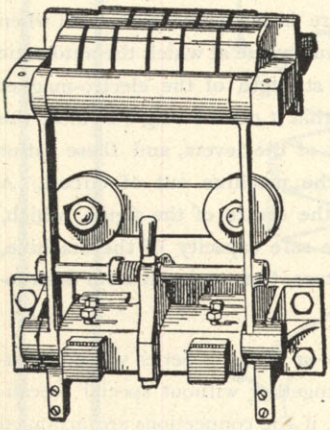
their share with a decrease of load. If the difference is slight, it may readily be compensated by means of the hand regulator increasing or decreasing the pressures of the machines, as the load varies or fluctuates. If, however, the difference is considerable, and the fluctuations of load very rapid, it becomes practically impossible to evenly divide the load by this means so that each dynamo takes up its proper share of the work.

Under such circumstances, the pressure at the bus bars is liable to great variations, and there is also great liability for the fuses of the overloaded dynamos to be blown, thus precipitating a general breakdown. To cause an equal division of the load amongst all the dynamos, under such circumstances, it is needful to insert a small resistance in the armature circuits of such dynamos as possess the straightest characteristics, or of such dynamos as take more than their share of an increase of load. By suitably adjusting or proportioning the resistances, the pressures at the terminals of all the machines may be made to vary equally under all variations of load, and each of the machines will then take up its proper share of the load.

Automatic Cutouts.—Shunt and other dynamos are always liable when working to have the pressure at their terminals reduced, either through a fault in the armature or field circuits, or through a hot bearing or other cause. When a number of shunt dynamos are running in parallel, and the pressure of one falls below that of the others, the load is transferred from the machine having the lower pressure to

the machine with the higher pressure, until when the pressure falls below a certain minimum value a reverse current is sent through the armature of the machine whose pressure has been reduced by the machines having the higher pressure.

FIG. 101.



AUTOMATIC SWITCH.

This results in the machine being driven as a motor, and in great sparking at the commutators of all the dynamos, and also in an overload of the driving dynamos, and probably in the blowing out of all the fuses. In order to prevent this occurring, shunt dynamos when running in parallel are each as a rule provided with an automatic switch, placed between one or both of the machine terminals and the omnibus bars, whose duty it is to switch off automatically the machine in the event of a reduction of its voltage from any of the above-mentioned causes. The principle and action of this instrument will be understood by reference to Fig. 101. Briefly described, the instrument consists of an electro-magnet, fixed upon a slate base, and shown in the upper portion of the figure, and an iron armature fixed to the ends of the pivoted levers of the switch, shown in the lower portion of the figure.

COUPLING OF DYNAMOS.

The electro-magnet is included in series with the switch and armature circuit, and while the pressure of the machine to which the instrument is connected remains at its normal value, the current flowing in its coils is sufficiently strong to enable it to hold up the iron armature against its pole pieces. If from any cause the voltage of the machine is reduced, the current flowing in its armature is decreased also, until when it falls below a certain minimum value at which the automatic switch is arranged to act, the strength of the electro-magnet has been so far diminished that it can no longer hold up the armature against the weight of the levers, and these latter therefore drop and switch the machine out of circuit. A fusible cutout is shown in the centre of the figure, which, when the current exceeds the safe capacity of the machine, melts, and cuts out the armature, thus saving it from destruction.

Coupling Series Dynamos in Series.—Series wound dynamos will run satisfactorily together without special precautions when coupled in series, if the connections are arranged as in Fig. 102. The positive terminal of one dynamo is connected to the negative terminal of the other, and the two outer terminals are connected directly to the two main conductors or bus bars through the ammeter A, fuse F, and switch S. If it be desired to regulate the pressure and output of the machines, variable resistances, or hand regulators R_1 R_2, may be arranged as shunts to the series coils, as represented, so as to devert a portion or the whole of the current therefrom.

COUPLING OF DYNAMOS.

Series Dynamos in Parallel.—Simple series wound dynamos not being well adapted for the purpose of maintaining a

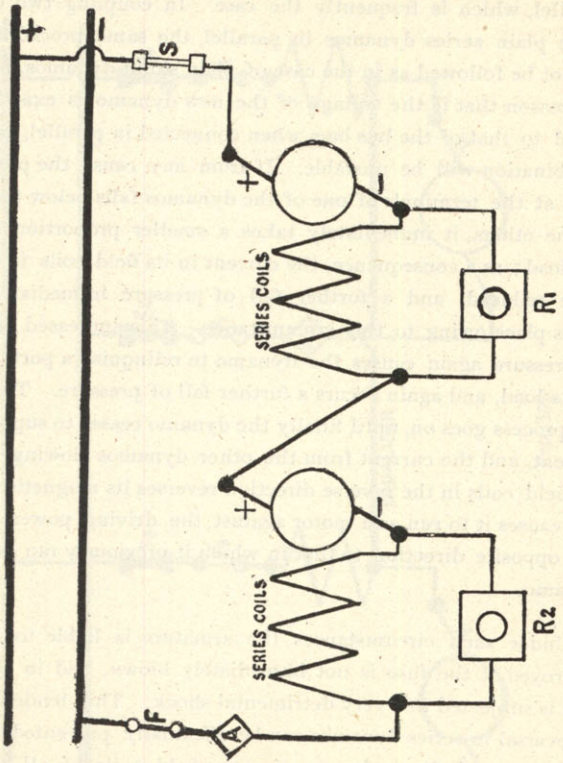


FIG. 102.

constant pressure, are seldom in practice coupled in parallel ; the conditions of working, however, derive importance from

the fact that compound dynamos, being provided with series coils, are subject to similar conditions when working in parallel, which is frequently the case. In coupling two or more plain series dynamos in parallel, the same procedure cannot be followed as in the case of plain shunt dynamos, for the reason that if the voltage of the new dynamo is exactly equal to that of the bus bars when connected in parallel, the combination will be unstable. If from any cause the pressure at the terminals of one of the dynamos falls below that of the others, it immediately takes a smaller proportion of the load; as a consequence, the current in its field coils is at once reduced, and a further fall of pressure immediately takes place owing to this circumstance. This increased fall of pressure again causes the dynamo to relinquish a portion of its load, and again occurs a further fall of pressure. Thus the process goes on, until finally the dynamo ceases to supply current, and the current from the other dynamos flowing in its field coils in the reverse direction reverses its magnetism, and causes it to run as a motor against the driving power in the opposite direction to that in which it previously ran as a dynamo.

Under such circumstances the armature is liable to be destroyed if the fuse is not immediately blown, and in any case is subjected to a very detrimental shock. This tendency to reversal in series dynamos can be effectually prevented by the simple expedient of connecting the field coils of all the dynamos in parallel, as was first suggested by Gramme. This is effected in practice by connecting the ends of all the

series coils where they join on to the armature circuit by a third connection, called the "equalizing connection," or "equalizer," as shown in Fig. 103. The immediate effect of

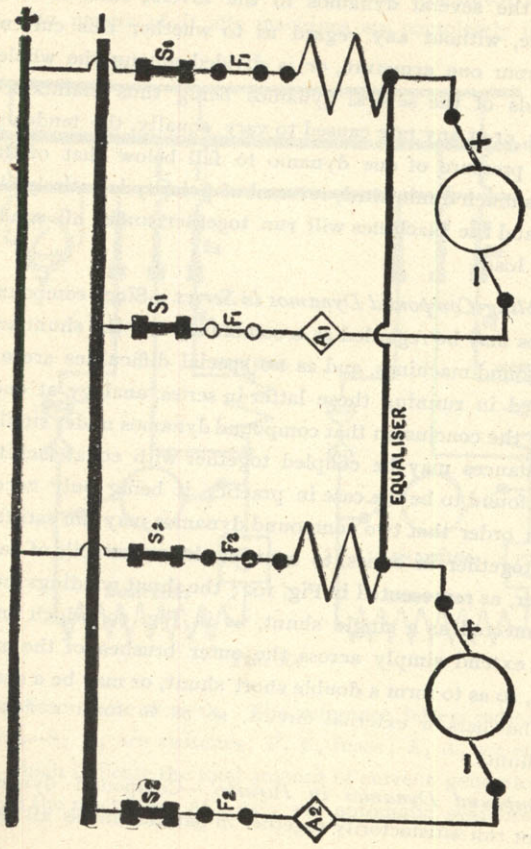


FIG. 103.

this equalizing connection is to cause the whole of the current generated by the plant to be divided among the series coils of the several dynamos in the inverse ratio of their resistance, without any regard as to whether this current comes from one armature, or is divided among the whole. The fields of the several dynamos being thus maintained constant, or at any rate caused to vary equally, the tendency for the pressure of one dynamo to fall below that of the others is much diminished, reversal of polarity is entirely obviated, and the machines will run together under all conditions of load.

Coupling Compound Dynamos in Series.—Since compound dynamos may be regarded as a combination of the shunt and series wound machines, and as no special difficulties are experienced in running these latter in series, analogy at once leads to the conclusion that compound dynamos under similar circumstances may be coupled together with equal facility. This is found to be the case in practice, it being only necessary, in order that two compound dynamos may run satisfactorily together in series, to connect the series coils of each together, as represented in Fig. 102; the shunt windings must be connected as a single shunt, as in Fig. 99, which may either extend simply across the outer brushes of the machines, so as to form a double short shunt, or may be a shunt to the bus bars or external circuit, so as to form a double long shunt.

Compound Dynamos in Parallel.—Compound dynamos will not run satisfactorily together in parallel unless all their

COUPLING OF DYNAMOS.

series coils are connected together by an equalizing connection, as in series dynamos. The method of arranging the connections as adopted in practice, being illustrated in Fig. 104. By means of it idle machines are completely discon-

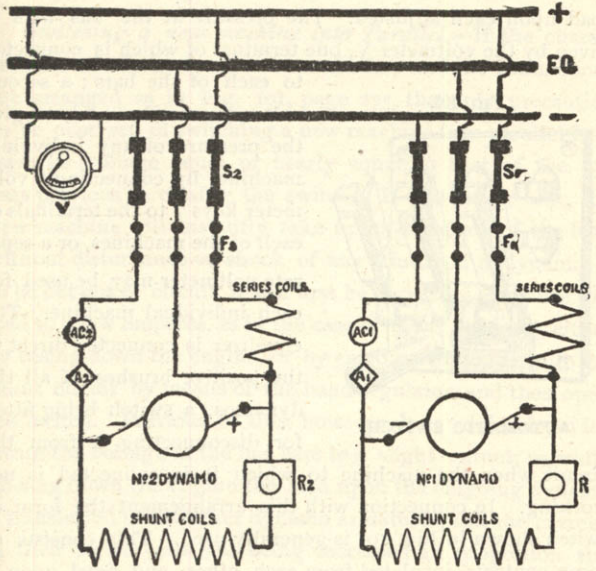
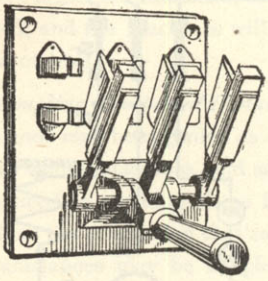


FIG. 104.

nected from those at work. The reference letters indicate as follows—S_1 S_2 are switches; F_1 F_2 fuses; A_1 A_2 are ammeters, which indicate the total amount of current generated by each of the machines; AC_1 AC_2 are automatic switches, ar-

ranged for automatically switching out a machine in the event of the pressure at its terminals being reduced through any cause ; R_1 R_2 are hand regulators, inserted in the shunt circuits of each of the machines, by means of which the pressures of the individual machines may be varied and the load upon each adjusted. The pressure at the bus bars is given by the voltmeter V, one terminal of which is connected to each of the bars ; a second voltmeter may be used, to give the pressure of any individual machine, by connecting "voltmeter keys" to the terminals of each of the machines, or a separate voltmeter may be used for each individual machine. The equalizer is connected direct to the positive brushes of all the dynamos, a switch being fitted for disconnecting it from the circuit when the machine to which it is connected is not working. In connection with this arrangement the form of switch shown in Fig. 105 is generally used. This consists of three contacts, insulated from each other, and fixed upon a slate base ; the two contacts at the sides are respectively connected to the positive and negative conductors, while the central contact is connected to the equalizer. The circuits are opened or closed simultaneously by means of three levers, which are forced between the contacts by the handle. These

FIG. 105.



AUTOMATIC SWITCH.

levers are each provided with removable knife contacts for taking the spark at breaking contact, and are insulated from each other, and rigidly fixed upon a spindle which is capable of a small angular movement in the bearings, shown in the lower part of the figure.

Switching a new machine into Parallel.—If the characteristics of all the dynamos are similar, and the connections are arranged as in Fig. 101, page 225, the only precaution to be observed in switching a new machine into parallel is to have its voltage equal, or nearly equal, to that of the bus bars previous to closing the switch. If this is the case, the new machine will instantly take up its due share of the load without disturbance or shock of any kind. If a dynamo is to be cut out of circuit, it will first be necessary to reduce the load to a few amperes, as in the case of shunt dynamos, either by easing down the engine, or by cutting resistance into the shunt circuit by means of the hand regulator, and then open the switch. Previous to this, however, it is advisable to increase the voltage at the bus bars to a slight extent, as while slowing down the engine the load upon the outgoing dynamo is transferred to the other dynamo armatures, and the current in their series coils not being increased in proportion the voltage at the bus bars is consequently reduced somewhat.

Equalizing Load.—When a number of compound dynamos of different outputs, size, or make are running together in parallel, it frequently happens that all their characteristics are not exactly similar, and therefore the load is unequally distributed amongst them, some being overloaded, whilst

others do not take up their proper share of the work. If the difference is small, it may be compensated by means of the hand regulator; if large, however, other means must be taken to cause the machines to take up their due proportion of the load. If the series coils of the several dynamos are provided with small adjustable resistances, in the form of German silver or copper ribbon inserted in series with the coils, the distribution of the current in the latter may be altered by varying the resistance attached to the individual coils, and thus the effect of the series coils upon the individual armatures in raising the pressure may be adjusted, and the load thus evenly divided among the machines.

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

QUES. *What is the meaning of the term "dialectrics"?*

ANS. It means the same as the word "non-conductor." Faraday gave the name dielactrics to what we call non-conductors.

QUES. *What is "a booster"?*

ANS. It is by this term that a dynamo is called which is arranged for use in an Edison incandescent light system to raise the pressure in a place where it is needed.

NOTE.—See pages 114 and 195.

SYMBOLS, ABBREVIATIONS AND DEFINITIONS.

QUES. *What does the letter "F" stand for?*

ANS. It is an abbreviation for Fahrenheit, as 10 F., meaning 10° Fahrenheit; or 10°—10° meaning ten degrees below zero.

The Fahrenheit scale is in use in the United States and England; upon it the temperature of melting ice is (32°) thirty-two degrees; that of condensing steam 180° F.

QUES. *What are Foucault-currents?*

ANS. These are the same as eddy currents, elsewhere explained and illustrated.

QUES. *What is the meaning of the word "deflection"?*

ANS. This is the movement out of the magnetic plane, due to disturbance by or attraction towards a mass of iron or other magnet.

QUES. *What is the meaning of the term "make and break"?*

ANS. It describes a current which is continually broken and started again. It is applied only where the "makes" and the "breaks" succeed each other with great rapidity.

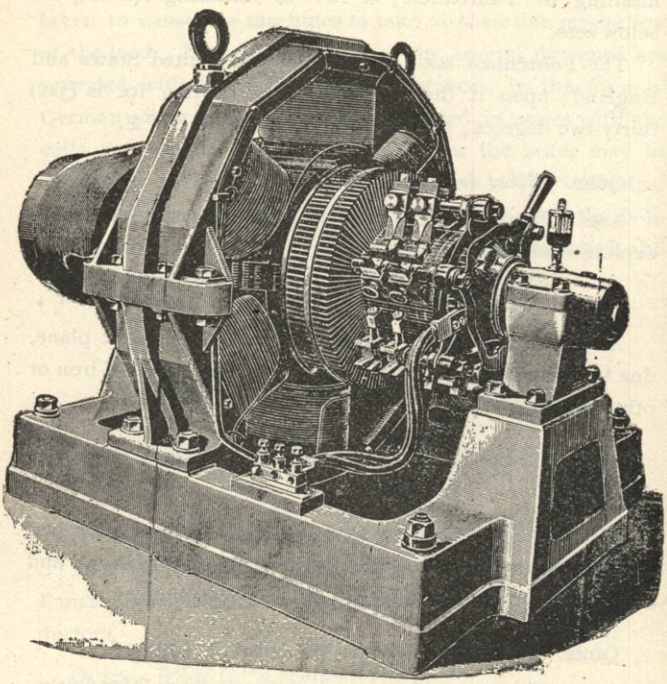
QUES. *What do the letters "B. W. G." express?*

ANS. This is an abbreviation of Birmingham Wire Guage.

QUES. *What is the meaning of "B. & S."?*

ANS, These are abbreviations of "Brown & Sharp" (American Guage).

FIG. 108.



MULTIPOLAR DYNAMO.

FAULTS IN ARMATURES.

The armature and commutator are the most vulnerable parts of a dynamo, and being subjected whilst rotating to various detrimental influences, are a prolific source of faults, the chiefest of which may be enumerated as follows:

(1) Short circuits in armature.

(2) Grounds in armature.

(3) Disconnections in armature circuit.

(4) Flats on commutator.

(5) Short circuits in commutator.

(6) Rough and uneven surface of commutator.

(7) Segments loose or knocked in.

(1.) *Short Circuits in Armatures.*—The classes of short circuits which occur in the armature are—(*a*) Short circuits in individual sections or coils; (*b*) Short circuits between adjacent coils; (*c*) Short circuits between sections through frame or core of armature; (*d*) Short circuits between sections through binding wires; (*e*) Partial short circuits in armature.

FAULTS IN ARMATURES.

(*a*) *Short Circuits in Individual Sections or Coils.*—This is an exceedingly common fault, which makes its presence known by a violent heating of the armature, flashing at the commutator, flickering of the light, and by a smell of burning varnish or overheated insulation. When these indications are present, the machine should be stopped at once, otherwise the armature is liable to be burnt out. The fault is due either to metallic dust lodging in the insulation between adjacent bars of the commutator, or to one or more convolutions of the coils coming into contact with each other, either through a metallic filing becoming embedded in the insulation or damage to the insulation. When the machine is stopped, the faulty coil, if not burnt out, can generally be located by running the fingers over the armature, by its excessive temperature over the rest of the coils, and by the baked appearance of the varnish or insulation. If the machine will not build, and it is suspected that the fault arises from short circuited armature coils, the field magnets should be excited by the current from a storage battery or another dynamo, and having raised the brushes from contact with the commutator, the armature should be run for a short time. In stopping, the faulty coil or coils may be located by the heat generated by the short circuit. When the dynamo is started to localize a short circuit, great precautions should be taken, and the machine only run for a few minutes at a time until the faulty coil is detected. A short circuited coil may also be located by the fall or potential method. Fig. 107 illustrates diagramatically this method of testing. Discon-

FAULTS IN ARMATURES.

nect the external and field circuits from the armature, and pass a large current—say from 20 to 100 amperes—from a

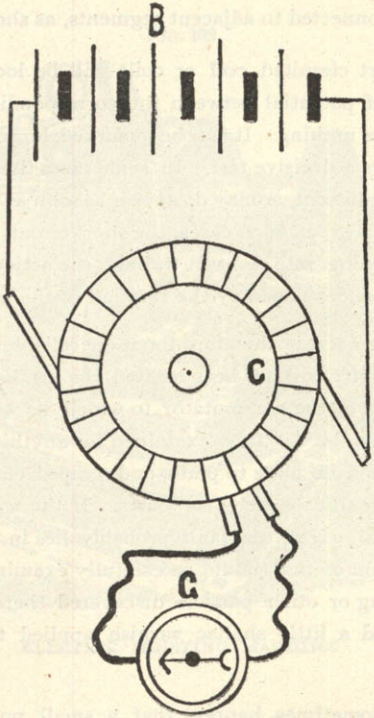


FIG. 107.

battery (B) or another dynamo through the whole armature by means of the brushes. Then, having previously well

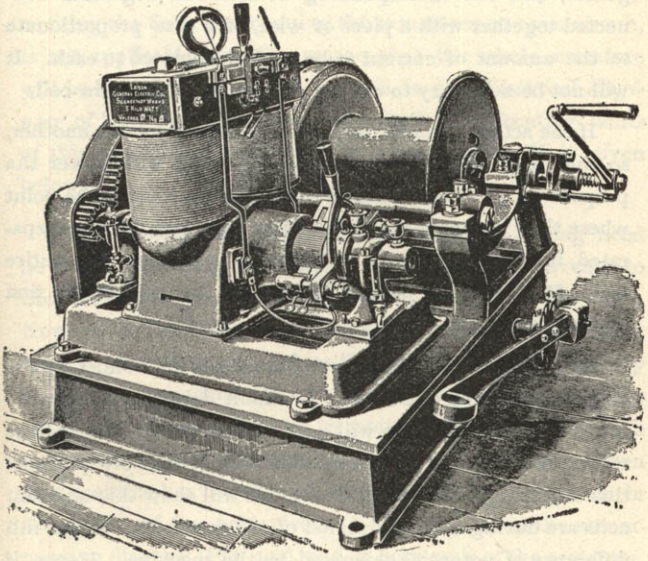
cleaned the commutator, measure the difference of potential between adjacent segments all round the commutator (C), by means of a voltmeter or galvanometer (G), the terminals of which are connected to adjacent segments, as shown.

The short circuited coil or coils will be located by the difference of potential between the corresponding segments being little or nothing. It may be remarked, however, that this is not always a decisive test. In some cases the short circuit may be intermittent, or may disappear as soon as the armature ceases to rotate. In such cases, the short circuit is caused by the wire coming into contact through the action of the centrifugal forces developed by the rotation of the armature.

The former test is therefore the more reliable in all cases. When the faulty coil has been located, the insulation between the segments of the commutator to which its ends are connected should be carefully examined for anything that may bridge across from plate to plate, and scraped clean from any adherent metallic particles or burrs. If the commutator is apparently all right, the fault probably lies in the winding. The insulation of this should be carefully examined, and any metallic filing or other particle discovered therein carefully removed, and a little shellac varnish applied to the faulty part.

It will sometimes happen that a small portion of the insulation has been abraded from two adjacent conductors, thus causing them to come into electrical contact with each other. In such circumstances a small boxwood or other

FIG. 108.



ELECTRIC HOISTING MACHINE

hardwood wedge, coated with shellac varnish, and driven in tightly between the wire, will generally effect a cure. If the faulty coil cannot be expeditiously repaired, and the dynamo is urgently wanted, the coil may be cut out of circuit altogether, and the corresponding commutator segments connected together with a piece of wire, of a size proportionate to the amount of current to be carried, soldered to each. It will not be necessary to cut out and remove the entire coil.

If the active portions only are separated from one another, so that they do not form a closed circuit, it will answer the purpose—*e. g.*, if the wires are cut with a chisel at the point where they pass over the ends of the core, and the ends separated, it will be quite as effective as removing the entire coil. It is wise, of course, to rewind the coil at the first opportunity.

(*b*) *Short Circuits between Adjacent Coils.*—Whilst in the ring armature the presence of this fault does not necessarily imply that the machine will not build, in the drum armature wound into a single layer of conductors it entirely prevents this occurring. Reference to Fig. 128 will show that adjacent coils are during a certain period of the revolution at the full difference of potential generated by the machine. Hence, if any two adjacent coils are connected together or short circuited, the whole of the armature will be practically closed on itself, any current generated flowing within the armature only, without passing to the external circuit.

Large drum armatures wound with compressed and stranded bars and connectors are particularly susceptible to this fault, a

FAULTS IN ARMATURES.

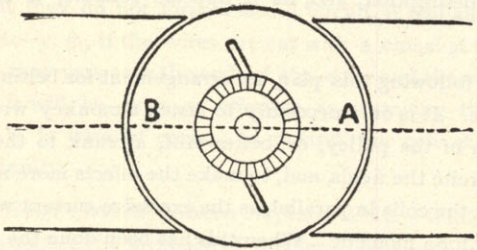
slight blow generally forcing one or more of the strands into contact with the adjacent bars, thus short circuiting the armature, and rendering it practically useless so far as the generation of current is concerned. In this class of short circuit in drum armatures, the method of locating the faulty coils by exciting the field, and running the armatures on open circuit, is not applicable, for the reason that the whole armature will be heated equally. Mr. Loomis, in the *Electrical Engineer* of New York, has described a method of locating faults of this description, and, as it appears reliable, it is given below:

"In following this plan, no arrangement for belting need be made. It is only necessary to fasten a monkey wrench to the rim of the pulley, or, better still, a crank to the shaft. Now, excite the fields, and, to make the effects more marked, connect the coils in parallel, as the excessive current will only be used for a moment. When this has been done the strongest man will scarcely be able to rotate the armature, and then only with extreme slowness, except at one position. When this position has been found, mark the armature at points in the centre of the pole pieces (A B), as shown in the accompanying diagram (Fig. 109), and at both ends of the armature. The explanation is that both halves of the armature oppose one another at this position; but when not at these points a continuous circuit is formed, and the resultant magnetic effect is enormous. As the 'cross' or 'short' circuit will be found at one of these four marked points, it becomes desirable to know in which one it is most likely to be found.

FAULTS IN ARMATURES.

Experience has shown that it is nearly always on the commutator end in the last half of the winding, where the wires pass down through the first half terminals. This applies to an unequal winding. In armatures where the windings are equal, it is as liable to occur at one point as at another. With this method a defect can be found and remedied in a few moments, for it has always been a simple matter to repair it

FIG. 109.



ARMATURE.

when discovered. These results can be observed in a perfect armature by connecting the opposite sections of the commutator.

The above will be understood to apply to armatures having Siemens winding." Faults of this description can frequently be discovered by a careful inspection of the windings of the armature without recourse to testing. When located, the fault can usually be repaired with a hardwood

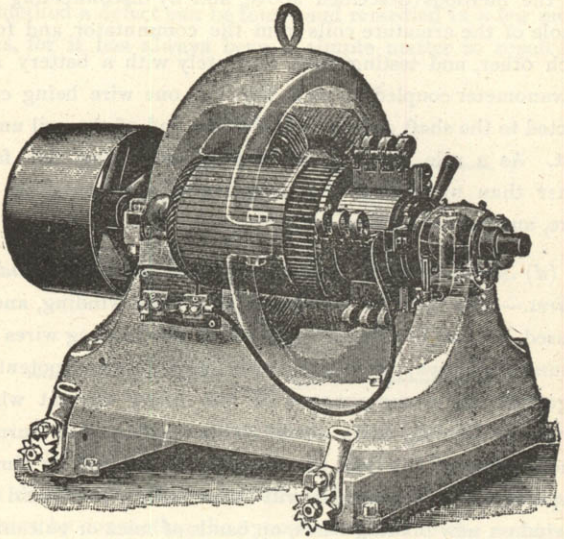
wedge, as explained above, or a piece of mica or vulcanized fibre cemented in place with shellac varnish.

(*c*) *Short Circuits between Sections through Frame or Core of Armature.*—The localization of this fault can be effected by the methods described above, and by disconnecting the whole of the armature coils from the commutator and from each other, and testing each separately with a battery and galvanometer coupled up as in Fig. 137, one wire being connected to the shaft and the other to the end of the coil under test. As a rule, there is no way of remedying this fault other than unwinding the defective coils, reinsulating the core, and rewinding new coils.

(*d*) *Short Circuits between Sections through Binding Wires.*—This fault is the result of a loose winding, and is caused by the insulation upon which the binding wires are wound giving way, thus bringing coils at different potentials together. As a consequence to the heavy current which flows, the binding wires are as a rule unsoldered or burned. The location of the fault can therefore be effected by simple inspection. To remedy, it will be necessary to unwind and rewind on new binding wires, on bands of mica or vulcanized fibre, soldering at intervals to obviate flying asunder.

(*e*) *Partial Short Circuits in Armatures.*—This is, as a rule, due to the presence of moisture in the windings. To remedy, the armature should be taken out and exposed to a moderate dry heat, or subjected to a current equal to that ordinarily given by the dynamo. Under the action of heat or

FIG. 110.



THE CINCINNATI MACHINE.

of this current the moisture will be gradually dispersed. When thoroughly dry, and whilst still warm, a coat of shellac or rubber varnish should be applied to the whole of the windings.

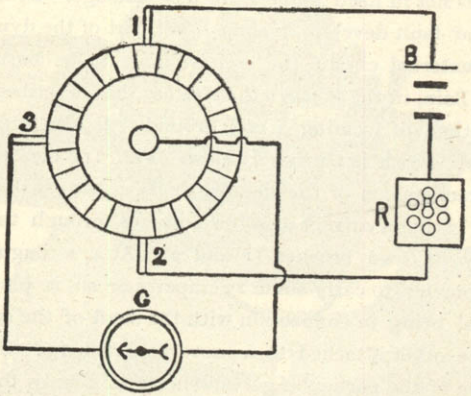
(2.) *Grounds in Armatures.*

(*a*) *Armature Coils Grounded or Connected to Core or Frame of Armature.*—When this fault is confined to a single coil, it is not in itself liable to do any damage. If, however, a similar fault develops in some other part of the dynamo, or in the external circuit, the coil is liable to be burned out. Mr. F. Bain, in the *Western Electrician*, has described a simple method of locating a coil grounded to the frame of an armature, which is reprinted below. Fig. 111 clearly shows the arrangements of the details. B is a battery or dynamo circuit, giving a current of a few amperes through the armature by its own brushes (1 and 2). At A, a roughly-made galvanometer, to carry some 25 amperes or so, is placed, one terminal being in connection with the shaft of the armature, and the other attached to a movable brush (3). Since the function of the particular galvanometer is simply to show a deflection when a current is passing, and to mark zero when there is none, a coil of thick wire, with a pocket-compass in the centre, will do all that is required, but care must be taken to remove it sufficiently far away from the disturbing effects of the armature magnetism. The manner of testing is as follows:

Assume a steady current to be flowing from battery (B) through the armature, touch the commutator with brush (3),

and a current will flow through (G). Slowly rotate the armature or the brush (3), until the galvanometer (G) shows no deflection. The coil in contact with 3 will be found to be *grounded* or connected to the frame. A hand regulator or rheostat (R) may be inserted in series with the battery or dynamo circuit to regulate the strength of the current passing.

FIG. 111.



ARMATURE AND RHEOSTAT.

The main advantage of this test is that the damaged coil can be located without unsoldering the coils from the commutator, which is sometimes a difficult operation without proper tools; and further, the fault can frequently be repaired without disconnecting any of the wires if its exact position be determined.

FAULTS IN ARMATURES.

(3.) *Disconnections in Armature Circuit.*—A partial or complete disconnection in the armature circuit is always characterized by heavy sparking at the commutator, but not, as a rule, by an excessive heating of the armature or slipping of the belt, and this enables this fault to be distinguished from a short circuit. The faulty part can always be readily located by the "flat" which it produces upon the surface of the commutator. The armature circuit being open at the faulty part, heavy sparking results at every half revolution as the brushes pass over it, and as a consequence the corresponding segments are "pitted" or "flattened" with respect to the others, and may easily be discovered on examination.

The fault may occur in either the commutator or in the coils of the armature. To ascertain whether it is in the latter, carefully examine the winding of the faulty coil. The defect may be sought for more particularly at the commutator end of the armature, as breaks in the wire are most frequent where the connections are made with the commutator segments. If no break can be discerned, try passing a heavy current through the faulty coil by means of the brushes. If a disconnection exists in sufficient contact to pass a current, the coil will be heated in the neighborhood of the disconnection, and may be discovered by running the fingers over the coil.

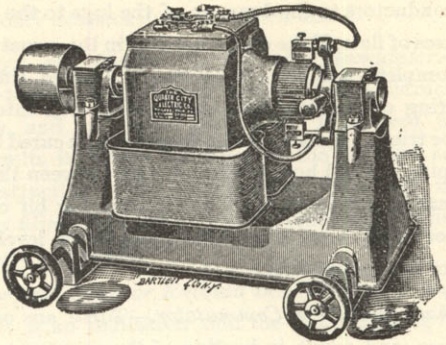
When located, the fault may be repaired by rewinding the coil, or carefully cleaning the broken ends and jointing. The fault may also be temporarily repaired by soldering the adjacent commutator segments together without disconnecting the coil.

FAULTS IN ARMATURES.

(4.) *Flats on Commutator.*—This is the name given to a peculiar fault which develops on one or more bars of the commutator. It is not confined to dynamos of bad design or construction, but frequently appears on those of the highest class, and may be recognized as a "pitting" or "flattening" of one or more segments. It is always accompanied by sparking at the brushes, and may be due to a periodical jumping of the brushes, caused by a bad state of the commutator, or a bad joint in the driving belt, or to a flaw, or a difference in the composition of the metal of the particular bar upon which it appears. But more frequently it may be traced to a more or less developed fault, such as a disconnection, either partial or complete, in the armature coil. The disconnection may occur either in the coil itself, or at the point where its ends make connection with the lug of the commutator, or at the point where the lug is soldered to the segment of the commutator.

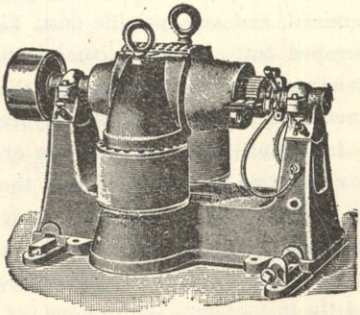
To remedy the fault, the brushes should be examined to see if any periodical vibration takes place. If such is the case, the cause should be removed, and the flat carefully filed or turned out, and the brushes readjusted. If it is due to a difference in the composition of the metal of which the segment is made, the flat will exist as long as the particular segment is in use, and will need to be periodically turned out if a new segment is not fitted into the commutator. Now that the construction of commutators has been improved, however, by the use of hard-drawn copper or phosphor-bronze segments, this fault is rarely due to this last-mentioned

FIG. 112.



THE BOSTON MACHINE.

FIG. 113.



THE PHILADELPHIA MACHINE.

cause. It is more frequently due to bad soldering, or jointing of the conductors to the lugs, or of the lugs to the segments. In all cases of flats, if the disconnection in the armature circuit is not complete, and cannot be readily located, the effect of re-soldering or sweating the ends of the coils into the lugs should be tried. Flats may also frequently be cured by drilling and tapping a small hole in the junction between the lug and the segment, and inserting a small screw, or bit of screwed copper or brass wire, afterwards filing down level with the surface of the commutator.

(5.) *Short Circuits in Commutator.*—These are of frequent occurrence, and result in heating of the armature and sparking at the brushes. They are caused either by metallic dust or particles lodging in the insulation between the segments, or by the deterioration of the commutator insulation.

To remedy, the insulation between the segments should be carefully examined, and any metallic dust, filings, or burrs cleaned or scraped out. When the commutator is insulated with asbestos or pasteboard (as is oftentimes the case in dynamos of continental make), short circuits very frequently occur through the insulation absorbing moisture or oil, which is subsequently carbonized by the sparking at the brushes. In faults of this description the only remedy is to expel all moisture from the commutator insulation by means of heat, and scrape out all metallic dust which may be imbedded in the surface of the insulation. If this does not effect a cure, it will be necessary to dig out the insulation, as far as possible, with a sharp tool, and drive in new insulation; oil

should not be used on commutators insulated with these materials, but only asbestos dust or French chalk.

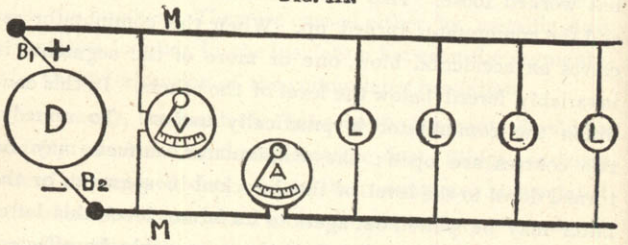
(6.) *Rough and Uneven Surface of Commutator.*—This fault is due to bad adjustment of brushes, bad construction of commutator, and to neglect generally. If allowed to continue, it results in heavy sparking at the brushes, and the eventual destruction of the commutator. The fault may be remedied by filing or turning up the commutator in the manner explained previously.

(7.) *Segments Loose or Knocked in.*—When the segments are loose, it is an indication that the clamping ring or cone has worked loose. This should therefore be tightened up, and the commutator turned up. When the commutator receives an accidental blow, one or more of the segments is invariably forced below the level of the others. In this condition the commutator is practically useless. To remedy, two courses are open: the commutator surface may be turned down to the level of the knocked-in segment, or the latter may be pulled out again to its former level, this latter being the preferable method, if it can possibly be effected. To pull out the segment, a hand vice is firmly clamped to the lug, or a loop of copper wire is passed round the conductor where it joins on to the commutator. A bar of iron to act as a lever is supported on a fulcrum over the commutator, and one end of the bar is passed through the loop or vice. On pressure being applied to the other end, the knocked-in segment can generally be brought up to its former level. The commutator can then be filed up with a dead smooth file.

METHOD OF MEASUREMENT.

As most installations are in practice provided with an ammeter and voltmeter, the current and pressure may be measured with facility. The instruments are arranged as represented in Fig. 114. D is a dynamo or other generator,

FIG. 114.



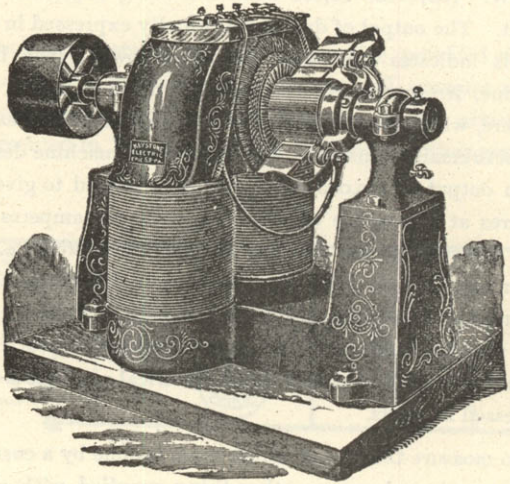
the positive and negative terminals of which are connected to the two mains M M between which the lamps L, L, are connected in parallel. To indicate the amount of current flowing in the circuit, an ammeter A is inserted in "series" in one of the mains and with the lamps, and therefore the whole of the current passing to the lamps passes through the ammeter, and is measured by the latter. A voltmeter V is connected across the two main leads, or in shunt with the dynamo, and meas-

ures the difference of potential between the two mains in volts. By taking simultaneous readings of the voltmeter and ammeter the energy being expended in the circuit can be ascertained by equation (1). For example, suppose the voltmeter to indicate 100 volts, and the ammeter 100 amperes, then by equation (1) $EC=W$. $100\times100=10{,}000$ watts are being expended in the circuit. The output of dynamos is usually expressed in watts, as this indicates the actual electrical power given by the machine, irrespective of the strength of the current, or its pressure, which may be varied to any extent so long as their product remains constant. For example, a machine designed for an output of 100,000 watts may be arranged to give 1,000 amperes at a pressure of 100 volts, or 10,000 amperes at 10 volts pressure, or 100 amperes at 1,000 volts pressure. The power required to drive the machine under these varying pressures and currents will remain the same, since their product remains constant. The power required to work incandescent and arc lamps and other electrical appliances is also expressed in watts.

To measure the rate at which work is done by a current in a wire, or in a lamp, or other thing supplied with electric power, we must measure both the *amperes* of current that are running through it, and the *volts* of electro-motive force that are actually applied at that part of the circuit, and having found the two numbers we must multiply them together.

For just as engineers express power mechanically as the number of "foot-pounds" expended in a given time, so the electrician expresses electric power as the number of "volt-

FIG. 115.



ERIE (PENNA.) MACHINE.

amperes." The more convenient name of "one *watt*" is given to the unit of electric power. Calculation shows that one "watt" or "volt-ampere" is equal to one seven-hundred-and-forty-sixth part of a horse-power.

NOTE.—A good dynamo will convert over 90 per cent. of the mechanical power supplied to it into electric power. Similarly a good motor will convert over 90 per cent. of the electric power supplied to it into mechanical power. Both mechanical power and electric power may be expressed in terms of the same units, either in horse-power, or in watts, or in kilowatts.

Approximate calculations of the horse-power required for a dynamo of any prescribed output are readily made. Multiplying the number of amperes of current which the dynamo is to yield, by the number of volts of pressure at which the current is supplied, gives the output in watts. Dividing by 746 gives the corresponding electric horse-power, which will be about 90 per cent. of the mechanical horse-power to be supplied to the shaft of the dynamo.

Ex. A dynamo is required to furnish 300 amperes at a pressure of 105 volts. Output is 31,500 watts = 42.2 horse-power (electrical). Therefore allow 46.9, or say 50 (mechanical) horse-power.

In the converse way we may calculate the requisite supply of electric power to a motor.

Ex. A motor is required to give an actual output of 5 horse-power. Multiplying by 746, we find it must give out 3,730 watts as mechanical power; which will be about 90 per cent. of the electrical power supplied to it. This will therefore need to be about 4,144 watts. If the supply is from mains that are at a pressure of 200 volts, the current required will consequently be a little over 21 amperes.

As an example of calculation of electric power the following may be taken. It was required to ascertain the power expended in maintaining a certain arc lamp. The voltmeter showed an electric pressure of 57 volts between the terminals of the lamp, and the amperemeter showed a current of 10.5 amperes running through it. The product is 598.5 watts. Dividing by 746 to bring to horse-power, we get 0.80, or eight-tenths of a horse-power.

DESIGNING A DYNAMO

As in all designing of machines, so with the designing of dynamos, experience is the ultimate guide. To design a machine which, when driven at a prescribed speed, shall yield any desired number of amperes of current at any given voltage, is a very simple matter to an engineer who has already had experiance in designing dynamos of the same general type, but of different output. To one who has designed two-pole continuous current machines for incandescent lighting it is a simple matter to design another machine of the same sort. But it would be to him by no means so easy from his experience only to pass to designing machines of a multipolar type, or to design alternate-current machines.

But to begin anew to design a dynamo without this kind of practical basis is a different matter. The first stage in understanding this is to examine carfully the design of some well-established machines, and to see how the dimensions of their several parts are adapted to their functions. It will then be an easier matter to work out any case for a fresh type of machine.

Calculations are needed to ascertain the proper sizes of the parts. Some of these calculations are purely electrical, others

magnetic, others mechanical, and some are of a wholly empirical nature founded on experience.

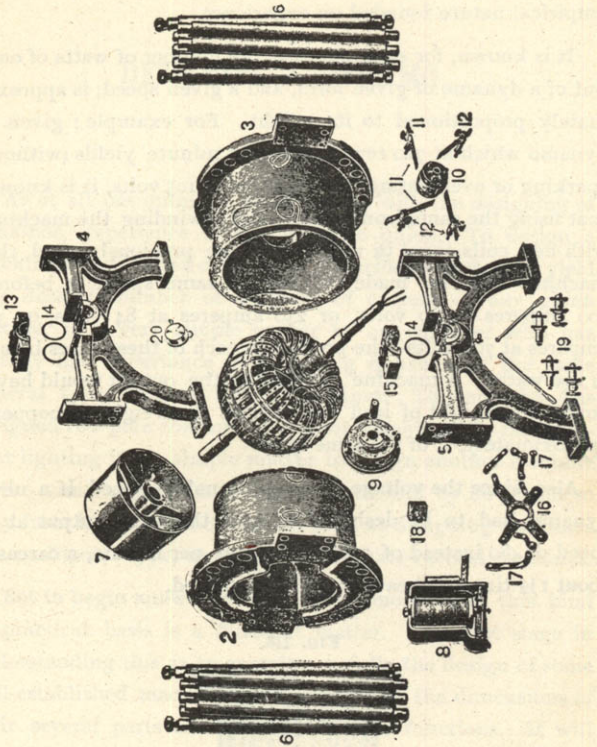
It is known, for example, that the number of watts of output of a dynamo of given form, and a given speed, is approximately proportioned to its weight. For example: given a dynamo which at 720 revolutions per minute yields (without sparking or overheating) 200 amperes at 105 volts, it is known that using the same iron carcase, and rewinding the machine with new coils equal in weight to those previously used, the machine may be made to give (at same speed as before) 300 amperes at 70 volts, or 250 amperes at 84 volts, or 30 amperes at 700 volts—the product in each of these cases being 21,000 watts. A machine for double the output would have double the weight of iron and double the weight of copper, approximately, if of the same type.

Also, since the voltage is proportional to speed, if a new dynamo had to be designed to give the same output at a speed of 480 instead of 720 revolutions per minute, a carcase about 1½ times as heavy would be required.

FIG. 116.

ELECTRIC LAMP.

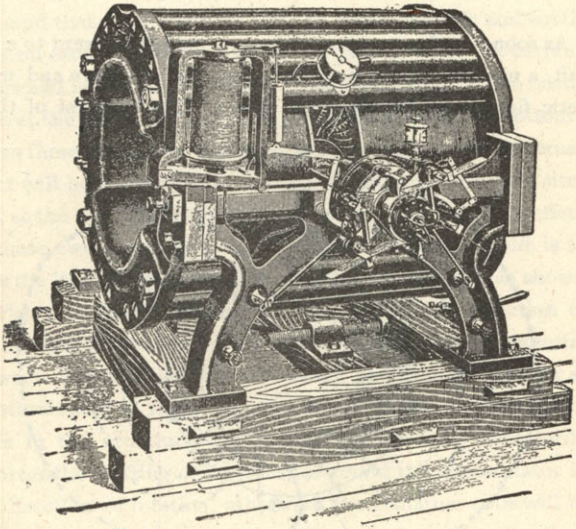
FIG. 117.



THOMPSON-HOUSTON ARC-LIGHT GENERATOR (PARTS).

LIST OF PARTS.

1. Armature (Ring Type).
2. Left Hand Field.
3. Right Hand Field.
4. Pulley Leg.
5. Commutator Leg.
6. Field Rods.
7. Pulley.
8. Automatic Regulator.
9. Air Blast.
10. Commutator.



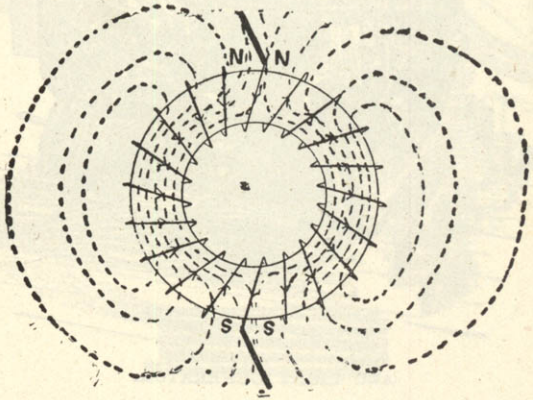
ARC LIGHT GENERATOR.

11. Brushes.
12. Brush Holders.
13. Pulley Bearing Cap.
14. Oil Rings.
15. Commutator Bearing Cap.
16. Yokes.
17. Regulator and Yoke Connection.
18. Vulcanite Connection Block.
19. Binding Post and Machine Connections.
20. Armature Short Circuiting Switch.

DISTORTION OF MAGNETIC FIELD IN THE DYNAMO.

As soon as a dynamo commences to supply current to a circuit, a number of reactions between the armature and magnetic field immediately takes place. The chiefest of these

FIG. 119.



reactions is the distortion of the magnetic field, and consequent shifting of the neutral points. This distortion of the magnetic field is directly due to the fact that the armature, when

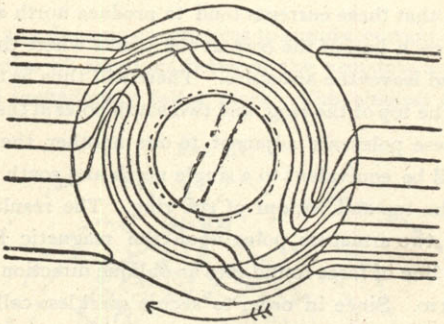
DISTORTION OF MAGNETIC FIELD.

working, becomes itself an electro magnet, the poles of which exert an attracting or repelling force upon the magnetic field. The nature of this armature magnetism will be understood by reference to Fig. 119. It will be seen that the currents generated in the windings on each side of the armature, by its motion in the magnetic field, are flowing from the top to the bottom of the ring. On applying the rule given on page 81, it will be found that these currents tend to produce north and south poles on each half of the core at the points where the current enters and leaves the armature. There will thus be two north poles at the top of the ring, and two south poles at the bottom; but as these poles are adjacent to one another, the external effect will be equivalent to a single north and south pole situated at the top and bottom of the ring. The resulant effect of these two armature poles upon the magnetic field is to twist the line of force round into an oblique direction as shown in Fig. 120. Since in order to secure sparkless collection of the current and to obtain the greatest difference of potential between the brushes, it is necessary to place these latter at points situated at right angles to the direction of the lines of force in the armature, the twisting of the lines necessarily involves the shifting of the brushes round the commutator in the direction of rotation, otherwise the armature coils will be short circuited by the brushes while actively cutting the lines of force, and considerable sparking at the brushes will result.

EDDY CURRENTS.

Another very important action which occurs when the dynamo is working is the production of *eddy currents* in different parts of the machine.

FIG. 120.



This term is applied to the currents which are always produced when a solid metallic mass is rotated in a magnetic field, or is subjected to the action of a magnetic field which is undergoing change in its intensity or strength, for the reason that the currents generated always tend to flow in more or less circular paths. When produced in large solid metallic masses, the strength to which these eddy currents attain is frequently very considerable, owing to the low electrical resistance of the masses in which they flow; and, in addition to consuming a large amount of energy, they frequently occasion a large and dangerous rise in the temperature. The

cores of armatures being made of iron, are, unless suitably constructed, subject to the detrimental influence of these eddy currents, as is also the case with the conductors wound upon the core if these are of large cross-sectional area. To entirely prevent the generation of these eddy currents is impossible; they can, however, be prevented attaining any considerable strength, by suitably interposing resistance in their path. With this object, the cores and conductors of armatures are *laminated*, or subdivided into a number of small parts, each of which is electrically insulated from the other by some insulating material.

COUPLING UP FIELD MAGNET COILS.

In coupling up the exciting coils of dynamo field magnets, the primary essential is to so arrange the connections of the coils that the magnetizing current flowing through them produces the requisite polarity in the respective pole pieces. In those field magnets provided wirh a single coil only (as in Fig. 76), no mistake can obviously be made; when two or more coils are used, however, it is possible to so arrange the connections that poles are produced in the yokes or other portions of salient pole field magnets; or in case of consequent pole field magnets, the connections may be so arranged that the coils neutralize each other, and no external field whatever is produced in the manner in which the coils of the various types of salient and consequent pole field magnets are coupled.

DISEASES OF DYNAMOS.

Taken as a whole, an electric machine is remarkably durable, and the cost of maintenance very small. There are only three parts that can really wear away—these are the two journals and the commutator. The shafts in nearly all machines are made of steel, and in some are even hardened and ground. Therefore the wear in the journals takes place mostly on the boxes, and these, being interchangeable, can be replaced in a few minutes and at small expense when worn out. The commutators, if they run without sparking, should last several years.

As there are virtually only three parts that really wear out, it might be supposed that the renewal of these parts would be all that would be required to keep the machine in perfect running order. But experience shows that such is not the case.

At least four-fifths of the mishaps and break-downs that occur with dynamos arise from causes more strictly within the province of the engineer than in that of the electrician. On the other hand, many of the mechanical faults that develop themselves in the machine might have been avoided had the engineer been possessed of a better knowledge of the electric and magnetic conditions which obtain in the running of the machine.

DISEASES OF DYNAMOS.

In the practical operation of dynamos and motors as well, the following is a list which covers nearly everything which should be first considered as faults or diseases :

First.—Failure to excite or generate, *i. e.*, when the machine is running the current does not flow.

Second.—Heating of armature, field magnets, commutator or brushes, or heating of the bearings.

Third.—Sparking at commutator.

Fourth.—Too high or too low speed.

Fifth.—Excessive noise or vibration.

Sixth.—Variation of voltage.

Each of these classes is distinct from the others, and when the "trouble" has been located, it will be seen that the remedying of one of the above list is nearly always all that is required—hence the importance of some study before applying the cure.

It is impossible to give complete direction for each occasion, but the lists will greatly aid the prompt and intelligent attendant.

FAILURE TO EXCITE.

The first point to be observed, if the machine fails to excite, is the position of the brushes upon the commutator. If these are not on or near the neutral points, the whole of the E. M. F. of the armature will not be utilized, and will probably be insufficient to excite the machine. If in doubt as to

FAILURE TO EXCITE.

the correct positions, the brushes should be rotated by means of the rocker into various points on the commutator, sufficient time, say five minutes, being given the machine to excite before moving them into a new position.

If the different points of contact of the connections of the machine are not kept thoroughly clean and free from oil, etc., it is probable that such resistance will be interposed in the path of the exciting current as to prevent the machine building or exciting. Each of the contacts should, therefore, be examined, and cleaned, and screwed up tight. The chief point to which attention should be given is the contact faces of the brushes and surface of the commutator. These are very frequently covered with a slimy coating of oil and dirt, which is quite sufficient to prevent the machine exciting.

In shunt and compound dynamos there is a certain critical speed below which they will not excite. If the normal speed of the machine is known, it can at once be seen whether the failure to excite arises from this cause, by measuring the speed of the armature with a speed indicator. In all cases it is advisable, if the machine does not excite in the course of a few minutes, to increase the speed to a certain extent. As soon as the voltage rises, the speed may be rednced to its regular amount.

Insufficient residual magnetism is a fault, although not of frequent occurrence, and it is almost impossible for it to take place if the field magnets are of cast-iron. It always occurs when the dynamo is a new one, or when the field magnets have been taken apart for repairs, etc. It may be remedied by passing the current from a few storage cells, or another

FAILURE TO EXCITE.

dynamo, for some time in the proper direction through the field coils. If a heavy current, such as is obtainable from a storage battery, is not available, and the machine is shunt or compound wound, a few Leclanché or dry cells will generally effect the purpose.

Reversed magnetism in fields is a fault of infrequent occurrence. It may be caused by the proximity of other dynamos, but is generally due to reversed connections of the field coils. Under such conditions the field coils tend to produce a polarity opposed to the magnetization to which they owe their current, and, therefore, the machine will refuse to excite until the field connections are reversed, or a current is sent from another dynamo or a battery through the field coils in a direction to produce the correct polarity in the pole pieces.

A dynamo may refuse to excite through some portion of its windings or connections being short circuited, for the reason that the field magnets are deprived of the necessary current required for building the machine. Short circuits most frequently occur in terminals, brush-holders, commutator, armature coils, field coils.

The terminals of the various circuits of the machine are liable to be short circuited, either through metallic dust bridging across the insulation, or through the terminals making direct contact with the frame of the machine. The various terminals should be examined, and if the fault cannot be located by inspection, they should each be disconnected from their circuits and tested with a battery and galvanometer.

EXCESSIVE HEATING OF DYNAMOS

The excessive heating of the constituent parts of a dynamo is probably the most common and at the same time the most annoying fault which arises in the working of the dynamo. It may be due to various causes, electrical or mechanical; and may occur in any one or more of the component parts of the dynamo:

(1.) Connections.
(2.) Armature, commutator, brushes.
(3.) Field magnets.
(4.) Bearings.

It may be detected by applying the hand to the different portions of the machine if low tension, or a thermometer if high tension, and also by a smell of over-heated insulation and paint or varnish. When this last indication is felt, it is advisable to stop the machine at once, otherwise the insulation is liable to be destroyed.

1. *Heating of Connections.*—This may proceed from either or both of the following causes:

(*a*) *Excessive Current.*—The terminals and connections will be excessively heated if a larger current passes through them than they are designed to carry. This nearly always

proceeds from an overload of the dynamo, and if this is rectified as directed in (4) "Overload of dynamo," the heating will disappear.

(*b*) *Bad Contacts.*—If the contacts of the different connections of the dynamo are not kept thoroughly clean and free from all grit, oil, etc., and the connections themselves are not tightly screwed up, great heating will result, and they may even be unsoldered.

2. *Heating of Armature, Commutator and Brushes.*—When excessive heating occurs in these portions of the dynamo, it may proceed from any of the following causes: (*a*) Excessive current; (*b*) Heated bearings; (*c*) Short circuits in armature or commutator; (*d*) Moisture in armature coils; (*e*) Disconnections in armature coils; (*f*) Eddy currents in armature core or conductors.

(*a*) *Excessive Current.*—When the dynamo is overloaded the temperature of the armature will rise to a dangerous extent, depending upon the degree the safe capacity of the machine is exceeded, and heavy sparking of the brushes will also result. If the overload is not removed as directed in (4) "Overload of Dynamo," the insulation of the armature may be destroyed.

(*b*) *Heated Bearings.*—If the bearings are heated, the heat may be conducted along the armature shaft and core, thus giving rise to excessive heating of the armature.

(*c*) *Short Circuits in Armature or Commutator.*—This fault results in sparking at the brushes, and in excessive

heating of one or the whole of the armature coils, and even in the burning up of the latter if a bad case. When the armature is overheated, and the defect does not proceed from an overload or the causes mentioned below, the dynamo should be immediately stopped and tested for this fault.

(*d*) *Moisture in Armature Coils.*—The effect of this fault being to practically short circuit the armature, a heating of the latter results. In bad cases steam or vapor is given off.

(*e*) *Disconnections in Armature Coils.*—This fault results in local heating of the armature, for the reason that resistance is interposed in the path of the current at the fracture. It always results in sparking at the brushes, and the heating being confined to the neighborhood of the disconnection.

(*f*) *Eddy Currents in Armature Core or Conductors*—When the construction of the armature core and conductors does not fulfil the necessary conditions required for the prevention of Eddy currents, such as the laminations not being sufficiently insulated or numerous enough, a great heating of the whole of the armature results, which may even extend to the bearings. There is no remedy for this defect other than the purchase of a new armature, or the entire reconstruction of the old. The fault may be detected by exciting the field magnets and running the machine on open circuit, with the brushes raised off the commutator for some time, when the armature will be found to be excessivly heated.

3. *Heating of Field Magnets.*—When the field magnets are found to be excessively heated, they should be tested for

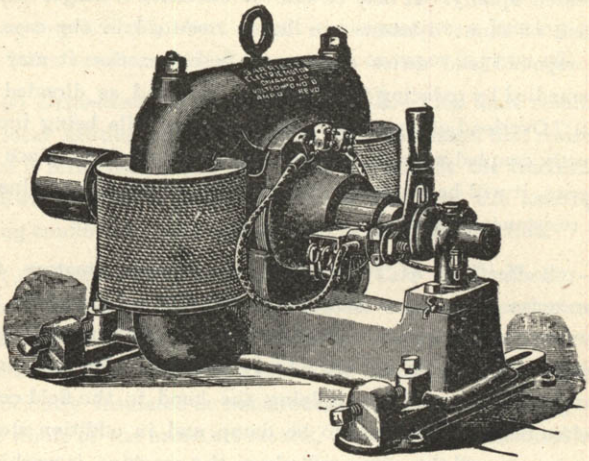
the following faults in the order given: (*a*) Excessive exciting current; (*b*) Moisture in field coils; (*c*) Short circuits in field coils; (*d*) Eddy currents in pole pieces.

(*a*) *Excessive Exciting Current.*—When the excessive heating arises from this cause, all the exciting coils will be heated equally. It may be due to excessive voltage, in the case of shunt dynamos; or to an overload in the case of compound and series dynamos. In either case it may be remedied by reducing the voltage or overload as directed in (4) "Overload of Dynamo." If due to the coils being incorrectly coupled up, *i. e.*, coupled up in parallel in place of series, it will be necessary to rectify the connections or insert a resistance in series.

(*b*) *Moisture of Field Coils.*—As in the armature, the presence of damp or moisture in the field coils tends to decrease the insulation resistance, thus in effect producing a short circuit with its attendant heating. The fault may easily be detected by applying the hand to the field coils, when they will be found to be damp, and in addition steam or vapor will be given off where the machine is working. The fault may be remedied by drying and varnishing the coils.

(*c*) *Short Circuits in Field Coils.*—This fault is characterized by an unequal heating of the field coils. If the coils are connected in series, the faulty coil will be heated to a less extent than the perfect coils. If, on the other hand, they are connected in parallel, the faulty coil will be heated to a

FIG. 121.



BARRIETT MACHINE (N. Y.)

greater extent than the perfect coils. The faulty coil can thus be easily located by this indication.

(*d*) *Eddy Currents in Pole Pieces.*—This fault may be due to defective design or construction of the armature. Toothed core armatures are particularly liable to cause this fault, if the teeth and air gap are not properly proportioned. The defect may also be occasioned by variation in the strength of the exciting current.

If due to this latter cause, it will be accompanied by sparking at the brushes. If a shunt dynamo, insert an ammeter into the shunt circuit, and note if the deflection is steady. If this is not the case, the variation in the current most probably proceeds from imperfect contacts thrown into vibration.

4. *Heating of Bearings.*—The heating of the bearings is of frequent occurrence in the working of dynamos, and is probably the most troublesome fault to which they are subject, as its origin is, as a rule, obscure. When the bearings heat excessively, so that the heat cannot be borne by the naked hand, and such simple remedies as the supply of fresh lubricant, or slacking back the caps of the bearings or the belt fails to remedy the trouble, the dynamo should be stopped, as it indicates something radically wrong.

The use of water on heated bearings has been recommended, but its use is questionable. No doubt it cools the bearing for the time being, and allows of the machine being run for a short time longer; but when the bearings are in

such condition as to need the application of water, probably as much damage is done to the journals and liners, through scoring, etc., as more than counterbalances any slight gain secured through running the machine while the bearings are heated. Removing the lubricators, and flooding the bearings and journals with ordinary or castor oil, tends to reduce the heating; or the effect of sulphur mixed with oil, and applied *direct* to the bearings, after removing the lubricators, should be tried. If these remedies fail, the machine should be stopped, and the cause of the heating ascertained. As a rule, heating of the bearings is due to—(*a*) Defective lubrication or bad oil; (*b*) Journals too tight; (*c*) Belt too tight; (*d*) Dirt, grit, etc., in bearings; (*e*) Rough or badly fitted journals or bearings; (*f*) Bent or badly turned shaft; (*g*) End pressure of shaft against bearings; (*h*) Armature incorrectly placed in armatnre chamber; (*i*) Badly proportioned bearings; (*j*) Bearings out of line; (*k*) Conduction of heat from armature.

(*a*) *Defective Lubrication or Bad Oil.*—When the bearings heat up, first examine the lubricators to see that they are full, and that they feed the lubricant properly, and that none of the feed or waste oil passages are clogged. It is advisable to pass the end of a piece of wire down each of the passages occasionally to clear them. The quality of the oil supplied to the lubricators should be of the best mineral oil, perfectly clean and free from grit. It is advisable not to use the waste oil for the dynamo again; but if used, see that it is well filtered. In some instances, hot bearings, due to defective

lubrication, have been remedied by cutting grooves obliquely in the face of the liners for the better circulation of the oil.

(*b*) *Journals too tight.*—If the caps of the bearings are screwed up too tight, the bearings are bound to heat up. As the armature spindle or shaft is not subjected to any reciprocal stresses, it is only needful to have the caps of the bearings screwed up hand tight. If the top brass does not bear upon the bottom brass, it may be necessary to scrape open the bearing a little, or insert a liner between the top and bottom brasses, until the spindle revolves freely by hand.

(*c*) *Belt too tight.*—Heating of the bearings may be due to too great a tension of the belt, caused either by an overload of the dynamo, or through too narrow a belt being used for the work, thus necessitating the dynamo being screwed up tightly upon the slides. When this is the case, the bearing next the pulley will be heated more than the other. The remedy is to reduce the load upon the dynamo, as directed in B (4) "Overload of Dynamo," or get a broader belt and pulley and run with some slack on the belt.

(*d*) *Dirt, Grit, Etc., in Bearings.*—The presence of the smallest quantity of grit in the lubricant or bearings will result in great heating of the latter. and in scoring of the shaft and liners, if not removed quickly. The machine should be stopped if possible, and the caps of the bearings taken off and the armature taken out of the bearings, and the latter carefully cleaned and scraped up smooth.

EXCESSIVE HEATING OF DYNAMOS.

If the journals are scored to any extent, it will be necessary to put the armature in the lathe and carefully file them up with a dead-smooth file before replacing. If the machine cannot be stopped at once, the lubricators should be made to feed very fast, or removed entirely, and the bearings continuously flooded with oil by means of an oil can until the machine can be conveniently stopped.

(*e*) *Rough or Badly Fitted Journals or Bearings.*—To ensure cool running, the journals should be perfectly smooth and true, and bear upon the surface of the liners throughout their entire length and width.

To ascertain if this is the case, the caps of the bearings should be removed, and a little "marking," composed of red lead or other coloring matter and ordinary oil, rubbed upon the journals. The caps should then be replaced, and the nuts screwed up to working pressure, and the armature rotated a few times. The caps should then be again removed, and the armature taken out, and the bearings examined. If the journals are bearing all over the surface of the liners, the fact will be indicated by the marking being distributed equally all over. If this is not the case, the projecting portions of the liners, as indicated by the marking, should be carefully scraped up and the armature put back again, and the bearings tested from time to time until the journals bear all over as indicated by the marking being equally distributed all over the surface of the liners.

(*f*) *Bent or Badly Turned Shaft.*—A bent shaft can be detected by rotating it with the hand. If bent, it will

"bind" at some portion of the revolution. If only slightly bent, the shaft should be placed in the lathe and carefully sprung back approximately straight, a light cut being taken off the journals to finally true it. The bearings will then need to be carefully refitted, as directed above. If badly bent, the only remedy is a new one. A badly turned shaft may be detected by means of the calipers and marking, as described above. If not truly circular, the marking will be unequally distributed over the *journals*.

(*g*) *End Pressure of Shaft against Bearings.*—This may be caused either by the shaft not being truly level, or through the belt not being truly aligned, or through there being no "end play." In the former case, carefully test the journals with a spirit-level, and pack up the dynamo or slide rails until perfectly level. If the belt does not run true upon the pulleys, it will be necessary to align the machine by moving it upon the sliding bedplate until the centre of the belt runs upon the centre of the pulley. If no end play exists, the shaft will be bound between the collars and the bearings, and the defect will be visible to the eye.

The correct amount of end play required varies with the size of the dynamo and method of driving adopted. In direct driven dynamos, if the collars of the journals are clear of the ends of the bearings, no end play is needed. In belt-driven dynamos, it is necessary to have from one-eighth to three-eighths of an inch of end play. In all cases it may be ascertained if the correct amount of end play is present by running the dynamo and observing, when *slight* pressure is

applied to one end of the shaft, if any end motion is produced. If no end motion is obtained, or a strong pressure is needed to obtain the latter, the face of the collar or end of the bearing against which the shaft bears should be filed or turned down, until the correct amount is obtained, when the machine is running.

(*h*) *Armature Incorrectly Placed in Armature Chamber.*—When the field magnet of a dynamo is excited, it has a tendency to attract the iron core of the armature. The direction and intensity of the attractive force varies with the type of field magnet and the position of the armature core in the armature chamber or bore. In vertical horse-shoe magnets of the over-type form (Fig. 77), if the armature is placed exactly in the centre of the armature chamber, there is a tendency for the armature to be attracted downwards, the intensity of the attraction varying with the strength of the field magnets. In large dynamos this attractive force may even amount to some thousands of pounds, and therefore, if the armature core is not placed in the armature bore in such position as to balance or nullify the attractive force, the bearings are liable to heat up through the excessive pressure brought to bear upon them. To counterbalance the attractive force, it is necessary in such dynamos to place the armature slightly above the centre of the armature chamber. In field magnets of the undertype form (Fig. 78), the attraction is in an upward direction, and therefore, as the weight of the core is lifted off the bearings, the latter are not so liable to heat up as in the case with the overtype form. In horizontal field

magnets (Fig. 79, etc.), the attractive forces act in opposite directions, and are therefore balanced; and in such dynamos the armature core may be placed exactly in the centae of the armature bore. A heating of the bearings is also liable to be occasioned through the attractive forces developed by the centre of the armature core not being parallel with the centre of the armature chamber or bore, or through the core being nearer one pole piece than the other. This may result from unequal wearing of the bearings, and therefore the bearings should either be re-lined or the bolt holes of the bearings readjusted, or the bearings packed up until the armature is correctly centred.

(*i*) *Badly Proportioned Bearings.*—The bearings will heat up if the wearing and bearing surfaces are not suitably proportioned for the work they have to perform. In such cases the bearings will heat at the first run of the machine. The only remedy is to put in new or larger bearings, or an additional one, if the shaft is long enough, and arrangements can be made to admit of this being done.

(*j*) *Bearings out of Line.*—This will be indicated by an unequal wear of the liners, and by the shaft binding or seizing. The remedy is to draw the bolt holes of the bearings until the bearings are correctly aligned with each other and with the armature bore.

(*k*) *Conduction of Heat from Armature.*—The bearings are liable to heat up through the heat developed by an overload or short circuit of the armature, or the production of eddy currents in the core being conducted along the shaft.

A CHAPTER OF "DON'TS."

"**Don't**" use waste on commutators.

"**Don't**" allow copper brushes to remain in contact with with commutators when the machine is at rest.

"**Don't**" get rattled at all the wires, cables and instruments at the switch board; they are all useful and most of them absolutely necessary, and they are no more complicated than the piping about your plant with which you are now familiar.

"**Don't**" fail to remember when the belts are put on the machines they are designed to run like any other piece of mechanical apparatus of similar weight and speed.

"**Don't**" forget to ask the man who is to set up new apparatus to give you printed or verbal directions for running it. If he is a "square man" he will cheerfully do this.

"**Don't**" fail to read the following, written by an engineer to a party seeking information.

NOTE.—"You will find that there is an armature made to revolve between two or more 'fields,' and that as the latter become magnetized they have an attraction that tends to hold the armature from turning, but the belt knows a 'good thing' and 'pushes it along,' thus generating current which the winding carries to the commutator, where it is picked off by the brushes and passed along to the circuit. If your circuit is kept whole and the machine in good order, there is less need of trouble with it than with a buzz saw."

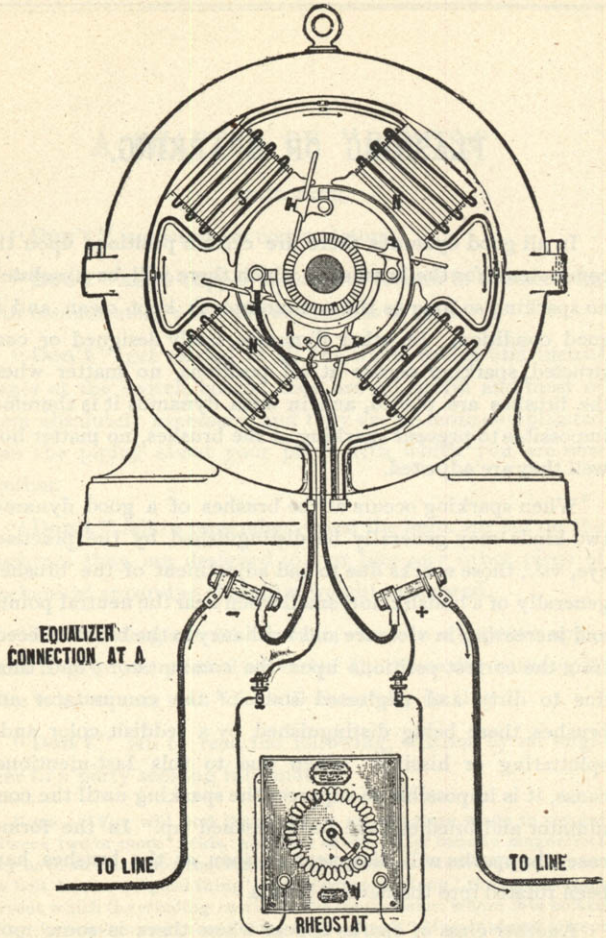
FLASHING OR SPARKING.

In all good dynamos there are certain positions upon the commutator for the brushes at which there will be absolutely no sparking so long as the commutator is kept clean and in good condition. In other dynamos, badly designed or constructed, sparking occurs at all positions, no matter where the brushes are placed, and in such dynamos it is therefore impossible to prevent sparking at the brushes, no matter how well they are adjusted.

When sparking occurs at the brushes of a good dynamo, two kinds may generally be distinguished by the practised eye, viz., those sparks due to bad adjustment of the brushes, generally of a bluish color, small when near the neutral points, and increasing in violence and brilliancy as the brushes recede from the correct positions upon the commutator; and those due to dirty and neglected state of the commutator and brushes, these being distinguished by a reddish color and a spluttering or hissing. When due to this last-mentioned cause, it is impossible to suppress the sparking until the commutator and brushes have been cleaned up. In the former case, the sparks will disappear as soon as the brushes have been rotated into the neutral points.

Another class of sparks appear when there is some more or less developed fault, such as a short circuit, or disconnection

FIG. 122.



FOUR POLE MACHINE WITH CONNECTIONS.

in the armature or commutator. These are similar in character to those produced by bad adjustment of the brushes, but are distinguished from the latter by their not decreasing in violence as the brushes are rotated towards the neutral points. Having distinguished the classes of sparks which appear at the commutator of a dynamo, it remains to enumerate the causes tending to produce sparking. These are:

(1.) Bad adjustment of brushes.

(2.) Bad condition of brushes.

(3.) Bad condition of commutator.

(4.) Overload of dynamo.

(5.) Loose connections, terminals, &c.

(6.) Disconnections in armature circuit.

(7.) Short circuits in armature circuit.

(8. Short circuits or disconnections in field magnet circuit.

1. *Bad Adjustment of Brushes.*—When sparking is produced by bad adjustment of the brushes, it may be detected by rotating or shifting the rocker, by the indication that the sparking will vary with each movement. To obtain good adjustment of the brushes, it will be necessary to rock them gently backwards and forwards, until a position is found in which the sparking disappears. If a position cannot be found at which the sparking disappears, it is probable that the brushes are not placed diametrically apart upon the commutator, or that the neutral points are not situated in their true theoretical positions upon the commutator through some defect in the winding, &c. In this last-mentioned case, the

brushes may be strictly adjusted to their theoretically correct positions before starting the machine; then, when the machine is started and the load put on, violent sparking occurs, which cannot be suppressed by shifting the rocker. If, however, one set of brushes only is observed, it will generally be found that, at a certain position, the sparking at the set of brushes under observation ceases or is greatly reduced, while sparking still occurs at the other set. When this position is found, the rocker should be fixed by the clamping screw, and the brushes of the other set at which sparking is still occurring adjusted by drawing them back or pushing them forward in their holders until a position is found at which the sparking ceases, at which they should be fixed. Correct position of the brushes upon the commutator and the suppression of sparking is a matter of great importance, and any time spent in carefully adjusting will be amply repaid by the decreased attention and wear of the brushes and commutator.

2. *Bad Condition of Brushes*—If the contact faces of the brushes are fused or covered with carbonized oil, dirt, &c., there will be bad contact between the brushes and commutator, and consequently great heating and sparking. Simple examination will generally reveal whether this is the case. The remedy is to remove the brushes, one at a time if the machine is running, clean, file if necessary, trim, and readjust. If the brushes are exceedingly dirty, or saturated with oil, it will be necessary to clean them with turpentine, benzoline, or soda solution, before replacing.

SPARKING AND FLASHING.

3. *Bad Condition of Commutator.*—If the surface of the commutator is rough, worn into grooves, or excentric, or had one or more segments loose, or set irregularly, the brushes will be thrown into vibration, and sparking will result. A simple examination of the commutator will readily detect these defects. The remedy for a rough commutator is to file it up while running with a dead-smooth file, afterwards polishing with finest emery cloth. If the commutator is untrue, the fact will be indicated when the machine is slowed down by a visible excentricity, or by holding the hand, or a stick in the case of high tension machines, against the surface while revolving, when any irregularity or excentricity will be apparent by the vibration or movement of the stick. The only remedy for an excentric commutator is to re-turn it as directed in the succeeding paragraph. Loose or high or low segments may be detected by the same means.

The remedy for high segments is to tap them gently down with a small hammer or mallet, and if possible tighten up the clamping cones at the ends of the commutator. If it is impossible to hammer the segments down, they should be filed down level with the rest of the commutator, or the commutator, re-turned. For low segments, the only remedy is to pull out the segments, or turn commutator down to their level.

Re-turning Commutator.—In re-turning the commutator, the armature should first be carefully taken out of the armature chamber, avoiding knocks or blows of any kind. The whole of the windings should then in order to prevent any particles

of metal finding their way on to the surface of the armature at the time the commutator is being turned, be entirely wrapped in calico or canvas before the armature is put into the lathe. The armature should on no account be rolled upon the floor, or subjected to blows or knocks while being put into the lathe, the winding is liable to be ruined if this takes place.

In re-turning the commutator, a sharp-pointed tool should be used with a very fine feed. A broad-nosed tool ought not to be used, as it is liable to burr over the segments. After turning, the commutator should be lightly filled up with a dead-smooth file, and finally polished with coarse and fine emery cloth. After the commutator has been turned and polished, the insulation between the segments should be lightly scraped with the tang of a small file to remove any particles or burrs of metal which may be likely to short circuit the commutator. The points where the armature wires are soldered to the lugs should also be carefully cleaned with a brush from any adherent copper dust, and should then receive a coat or two of shellac varnish. While the commutator is being turned, care should be taken that the setting marks for the adjustment of the brushes are not turned out if these are present. The same care should be used in putting the armature back into the armature chamber as was used in taking it out, otherwise the insulation is liable to be seriously damaged.

4. *Overload of Dynamo.*—It may happen through some cause or other that a greater output is taken from the machine

than it can safely carry. When this is the case, the fact is indicated by excessive sparking at the brushes, great heating of the armature and other parts of the dynamo, and possibly by the slipping of the belt (if a belt-driven machine), resulting in a noise. The causes most likely to produce overload are:—(*a*) Excessive voltage; (*b*) Excessive current; (*c*) Reversal of polarity of dynamo; (*d*) Short circuits or grounds in dynamo, or external circuits.

(*a*) *Excessive Voltage.*—This will be indicated by the voltmeter, and by the brightness of the pilot lamp. It may be caused either by excessive excitaiton of the field magnates, or by excessive speed. In the former case, resistence should be introduced into the field circuit to diminish the current flowing therein if a shunt machine; or if a series machine, a portion of the current should be shunted across the field coils by means of a resistance arranged in parallel with the series coils; or the same effect may be produced in both cases by reducing the speed of the armature if this is possible. If due to excessive speed, which will be indicated by a speed indicator, the natural remedy is to reduce the speed of the motor driving the dynamo, or, if this is not possible, insert resistance into the dynamo circuit, as described above.

(*b*) *Excessive Current.*—This will be indicated by the ammeter. If the dynamo is supplying arc lamps, the excessive current may possibly be caused by the bad feeding of the lamps. If this is the case, the fact will be indicated by the oscillations of the ammeter needle; and by the unsteadiness

of the light. If incandescent lamps are in circuit, the fault may be caused by there being more lamps in circuit than the dynamo is designed to carry. Under such circumstances, another dynamo should be switched into circuit in parallel, or, if this is not possible, lamps should be switched off until the defect is remedied. When electro-motors are in circuit, sparking frequently results at the dynamo commutator, owing to the fluctuating load. In such cases the brushes should be adjusted to a position at which the least sparking occurs with the average load.

(*c*) *Reversal of Polarity of Dynamos.* — When compound or series wound dynamos are running in parallel, their polarity is occasionally reversed while stopping by the current from the machines at work. Under such conditions, when the machine is again started, the E. M. F. of one is added to that of another, or the machines are connected in series, so that a closed circuit is formed, and as a consequence an enormous current results. Before the machine can be again coupled in parallel, it will be necessary to send a current through the field coils in the reverse direction.

(*d*) *Short Circuits or Grounds in Dynamo or External Circuits.*—A dynamo is liable to be overloaded through bad insulation of the dynamo or external circuits, resulting in a considerable leakage of current, in which case the ammeter will probably not indicate the fact. To ascertain if this is the case, connect a piece of insulated wire to one of the terminals

of the machine while running, and then make short momentary contacts with the ground through a water pipe, or frame of the dynamo, or other body in good connection with the earth. If a flash occurs, it proves that the insulation is defective somewhere. This test should be applied to each of the terminals in turn. The fault should next be located by taking the mains to the external circuit out of the terminals of the machine, and again testing as before. If a flash again occurs, it proves that the defect exists in the dynamo, which should be stopped, and the terminals, etc., tested with a battery and galvanometer. It must be clearly understood that a fault of this description is just as likely to occur in the external circuit, and therefore, if after removing the mains from the terminals of the machine, and again testing, the flash disappears, it may be taken that the fault is in the external circuit, which should be tested in a similar manner to the dynamo.

(5.) *Loose Connections, Terminals, &c.*—When any of the connecting cables, terminal screws, etc., securing the different circuits are loose, sparking at the brushes, as a rule, results, for the reason that the vibration of the machine tends to continually alter the resistance of the various circuits to which they are connected. When the connections are excessively loose, sparking also results at their points of contact, and by this indication the faulty connections may be readily detected. When this sparking at the contacts is absent, the whole of the connections should be carefully examined and tested.

SPARKING AND FLASHING.

(6.) *Disconnections in Armature Circuit.*—If there is a broken circuit in the armature, as sometimes happens, through a fracture of the armature connections, &c., there will be serious flashing or sparking at the brushes, which cannot be suppressed by adjusting the rocker. As a rule it results in the production of "flats" upon one or more bars of the commutator. If it is impossible to stop the machine, the sparking may be much reduced by placing one of the brushes in each set a little in advance of the others, so as to bridge across the disconnection. If the machine is only provided with one brush on each side of the commutator, a bit of copper wire may be fixed in each holder, so as to project slightly in front of the brushes, and thus bridge over the broken circuit.

(7.) *Short Circuits in Armature Circuit.*—This fault is indicated by sparking at the commutator, and in bad cases by an excessive heating of the armature, dimming of the light, and slipping of the belt, and in the case of drum armatures by a sudden cessation of the current.

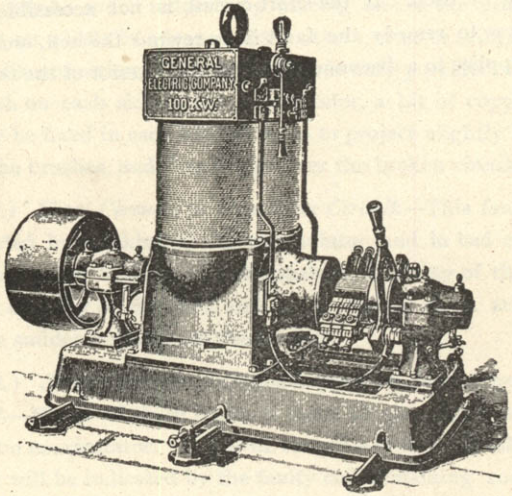
(8.) *Short Circuits or Disconnections in Field Magnet Circuit.*—Either of these faults is liable to give rise to sparking at the commutator. If one of the coils is short circuited, the fact will be indicated by the faulty coil remaining cool while the perfect coil is overheated. The fault may arise through some of the connections to the coils making contact with the frame of the machine or each other. To ascertain this, examine all the connections, and test with a battery and galvanometer. A total disconnection in one or more of the field coils may readily be detected by means of the battery and

galvanometer. A partial disconnection is not, however, so readily discovered, for the reason that the coil wires may be in sufficiently close contact to give a deflection of the galvanometer needle. The only methods of detecting this fault is by measuring the resistance of the coils with an Ohmeter or Wheatstone Bridge, or by placing an ammeter in circuit with each coil in turn, and comparing the amount of current flowing in each. If the short circuit is not accessible, the only way to remedy the fault is to rewind the coil, and the same applies to a disconnection if in the interior of the coil.

LIST OF PARTS OF EDISON BIPOLAR GENERATORS.

1. Rails.
2. Adjusting Rail-Bolts.
3. Bed-Plate.
4. Zinc Bases for Fields.
5. Pole Pieces.
6. Conductor Rods.
7. Field Coils and Cores.
8. Lower Screws, field cores to pole pieces.
9. Bolts for attaching keeper to pole pieces.
10. Washer for same.
11. Keeper.
12. Backboard and field coil terminal blocks.
13. Bolts for same.
14. Head-board.
15. Bolts for same.
16. Rib Side-Plate.
17. Panel Side-Plate for Name-plate.
18. Pillow Block Base, Commutator End.
19. Pillow Block Complete, Pulley End.
20. Drip Cock for self-oiling bearings.

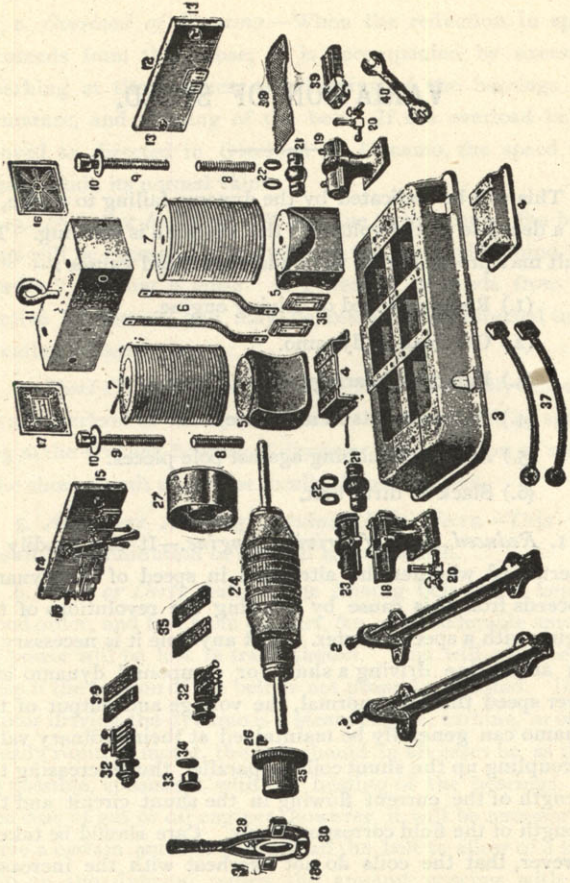
DIRECT CURRENT BIPOLAR GENERATORS.



EDISON SYSTEM.

21. Bearing Sleeve for self-oiling bearings.
22. Rings for self-oiling bearings.
23. Cap for Pillow Block. Commutator end.
24. Armature Complete.
25. Commutator Complete.
26. Comt. Cap for ends of Armature coils.
27. Armature Pulley.
28. Brush Yoke.
29. Bolt for same.
30. Spring Washer for adjusting tension.
31. Thumb Screw for Yoke.
32. Brush-holder Complete.
33. Insulating Blocks for Brush-Holder.
34. Insulating Washer for Brush-Holder.
35. Brushes.
36. Foot-Boards.
37. Brush-Holder Cables.
38. Wire Screen for protecting Armature.
39. Brush Filing Jig.
40. Generator Wrench.

FIG. 124.



PARTS OF

EDISON BIPOLAR GENERATOR.

VARIATION OF SPEED.

This will be indicated by the dynamo failing to excite, or by a decrease of the voltage if the machine is working. The fault may proceed from the undermentioned causes:—

(1.) Reduced speed of driving engine.

(2.) Overload of dynamo.

(3.) Defective bearings.

(4.) Short circuits in armature.

(5.) Armature rubbing against pole pieces.

(6.) Slack or dirty belt.

1. *Reduced Speed of Driving Engine.*—It can readily be ascertained whether the alteration in speed of the dynamo proceeds from this cause by counting the revolutions of the engine with a speed counter. If at any time it is necessary to run an engine driving a shunt or compound dynamo at a lower speed than the normal, the voltage and output of the dynamo can generally be maintained at their ordinary value by coupling up the shunt coils in parallel, thus increasing the strength of the current flowing in the shunt circuit and the strength of the field correspondingly. Care should be taken, however, that the coils do not overheat with the increased current.

VARIATION OF SPEED.

2. *Overload of Dynamo.*—When the reduction in speed proceeds from this cause, it is accompanied by excessive sparking at the brushes, and heating of the bearings and armature, and slipping of the belt. If the overload be removed as directed in Overload of Dynamo, the speed will again attain its normal value.

3. *Defective Bearings.*—When due to this cause, the bearings will be excessively heated, and the shaft will "bind" or "seize," making a noise. It generally proceeds from defective lubrication, and may be remedied as directed in (4) Heating of Bearings.

4. *Short Circuits in Armature.*—This practically amounts to an overload of the dynamo, and is accompanied by sparking at the brushes, heating of dynamo, and reduction of speed. The short circuit should be localized and repaired.

5. *Armature Rubbing Against Pole Pieces.*—This will result in a diminution of speed if not remedied.

6. *Slack or Dirty Belt.*—If the driving belt is not kept in good order, and free from oil, dirt, &c., a considerable amount of power will be lost in transmission. This will also be the case if the tension of the belt is not properly adjusted. If the motor driving the dynamo is a steam engine, turbine, or other steady running motor, the belt should in all cases be as tight as possible, consistent with the heating of the bearings. In the case of gas or oil engines, however, it will be necessary to have a certain amount of slack on the belt to allow of a little slip on the dynamo pulley, the amount varying with the irregularity of speed of the driving motor.

VARIATION OF VOLTAGE.

The pressure at the terminals of either shunt, series, or compound dynamos is liable to vary or fluctuate from various causes. In plain shunt or series wound dynamos a variation of pressure under a varying load follows as a consequence to the construction of the machine. A distinction, therefore, needs to be drawn between this natural variation of pressure and an abnormal fluctuation, which also affects compound dynamos, which may occur from time to time in the working of such machines. The causes tending to produce a fluctuation of voltage are :—

(1.) Irregularities of speed.

(2.) Bad joints in belt.

(3.) Short circuits or disconnections in armature circuit.

(4.) Short circuits or disconnections in field magnet circuit.

(5.) Incorrect connections.

1. *Irregularities of Speed.*—Any cause tending to produce a variation in the speed of the dynamo is responsible for a variation of voltage. Steam engines, turbines, &c., give as a rule very little trouble in regard to irregularities of speed. In the case of gas and oil engines, however, an unsteadiness of

speed is always present, owing to their mode of action and construction. Before such motors can be used successfully in driving dynamos, this unsteadiness of speed needs to be reduced and compensated as far as possible. With this object, such engines, when used for driving dynamos, are therefore fitted with extra heavy fly-wheels, and a fly-wheel is also fitted upon the armature spindle of the dynamo. In driving with such engines, the governors and valves are adjusted, if possible, to give an explosion at every revolution of the fly-wheel, and any little irregularity of speed is then compensated by varying the tension and slip of the belt on the dynamo pulley.

2. *Bad Joints in Belt.*—If the belt is not jointed in a suitable manner, it will cause a fluctuation of voltage, and a flickering of the light as the joint passes over the pulley. The belt should in all cases be soft and pliable, and made endless by a long spliced joint, or a butt joint with fasteners, or an endless link belt should be used. Lapped joints should on no account be used.

3. *Short Circuits or Disconnections in Armature Circuit.*—When either of these faults is present, a periodical fluctuation of voltage will be set up, accompanied by sparking at the brushes. When this occurs the machine should be stopped at once and the fault located and repaired.

4. *Short Circuits or Disconnections in Field Magnet Circuit.*—Either of these faults will give rise to a dimiuution or increase of voltage. To locate the faults, the entire field circuit should be tested and examined.

VARIATION OF VOLTAGE.

5. *Incorrect Connections.*—If on starting a machine for the first time, or after repairs, the voltage is either above or below its normal value, it is possible the variation may be the result of incorrect connections. The whole of the connections, including the armature, brushes, flexible leads, and field coil connections, should therefore be examined and verified.

EXCESSIVE NOISE OR VIBRATION.

The causes tending to produce excessive noise or vibration in a dynamo are :—

(1.) Bad foundations.
(2.) Loose screws, connections, &c.
(3.) Belt joints.
(4.) Bad adjustment of brushes.
(5.) Knocking of shaft or pulley against bearings.
(6.) Armature out of balance.
(7.) Armature knocking or rubbing against pole pieces.
(8.) Straining of shaft couplings.

These reasons for noise and vibration are self-explaining and the mere reading of them will suggest the appropriate remedy—but perhaps the more readily with the following paragraphs :

EXCESSIVE NOISE.

Excessive vibration can only be due to want of proper balance in the armature.

Vibration of another kind may nevertheless be disastrous to the dynamo, even in a well balanced machine, and this is caused by its not being firmly attached to a proper foundation.

Continuous-current machines should run practically silently; the belt will make far more noise than any part of the dynamo.

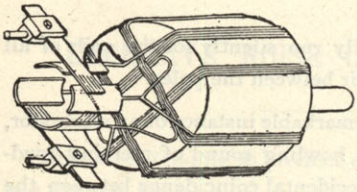
Alternators do not usually run silently for the coils of all disk armatures churn the air between the poles.

A case is recorded of a remarkable instance of an alternator, which emitted a sustained howling sound of piercing loudness. The cause was an accidental coincidence between the number of alternations and the natural vibration period of some of the solid iron parts.

WINDINGS OF ARMATURES.

Figs. 125 and 126 are simple diagrams showing the way in which wire is wound on drum and ring armatures, respectively. In both figures the coils are shown separated to more readily illustrate the principle. A little examination of the figures will show that each section of the coil is connected to the next in order to it; the whole of the windings constituting, therefore, a single *closed coil*.

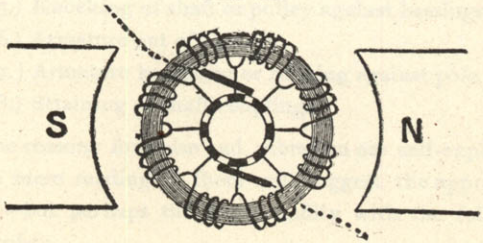
FIG. 125.



DRUM WINDING.

Also the end of each section and the beginning of the next are both connected with a segment of the commutator.

FIG. 126.



RING WINDING.

WINDING OF ARMATURES.

Let it be remembered that in *closed-coil armatures*, whether of the "ring" or the "drum" type, there are usually as many segments to the commutator as there are *sections* or groups of coils in the circuit of the armature. In the case of *open-coil armatures*, the separate coils are not connected up together in series, and a special form of commutator is used instead of the usual arrangement of a large number of parallel bars.

The principle of the ring or gramme armature is shown in Fig. 70. An iron ring capable of revolving upon an axis is arranged in the magnetic field between the poles N and S of an electro magnet. Upon this ring is wound a number of coils or loops of insulated copper wire, so as to cover the whole of the surface of the iron ring. The ends of each of the coils are connected to the ends of the adjacent coils, so that a continuous closed spiral is formed all around the ring; and, at the points where connection is made between the coils, connection is also made to strips of copper, which are insulated from each other and arranged around the axis of rotation into a circular commutator, as shown in the figure, against the two strips situated at opposite ends of a diameter press, two metallic brushes, B1, B2, which, remaining stationary, serve to convey the current generated in the coils of the armature to the external circuit E.

The arrangement of the lines of force in the magnetic field between the two poles N and S, when the ring is inserted therein is shown in the dotted lines in the figure.

WINDING OF ARMATURES.

From this it will be seen that the lines of force issuing from the north pole pass by way of the armature core to the south pole of the magnet, one-half of the lines passing through the upper portion of the core and the other half passing through the lower portion of the core. Owing to this peculiar arrangement, a very intense magnetic field is created between the outer surface of the armature core and the polar faces, whilst the interior space within the core remains almost entirely free from lines of force.

The drum or Siemen's type of armature differs essentially from the ring armature only in the manner in which the conductors are arranged upon the iron core. In the ring armature the core consists of a ring, and is overwound with conductors passing along the outer surface and through the interior; in the drum armature, the core is in most cases a ring also, or may be regarded as a ring, and is overwound with conductors passing along the outer surface, but in place of passing through the interior the conductors are carried completely around it axially, in the manner represented in Fig. 127.

This shows a drum armature in perspective, upon which only two adjacent conductors or coils have been wound. Since the windings of the drum armature pass over the ends of the core, it is impossible to represent the whole of them in perspective, and, therefore, they are exhibited diagramatically in Fig. 128, which illustrates what is known as a right-handed winding, with eight-part commutator (see in cut a, b, c, d, etc.). In the figure shown, the windings are supposed to be

WINDING OF ARMATURES.

viewed from the commutator or front end of the armature. The windings passing along the length of the drum are represented by the small circles upon which are marked the dots and crosses denoting the direction of the E. M. F., as in the ring armature. The connections passing across the back end of the drum are represented by the dotted lines; those upon the front end by full lines.

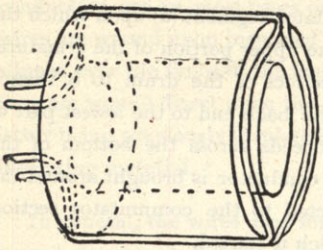


FIG. 127.

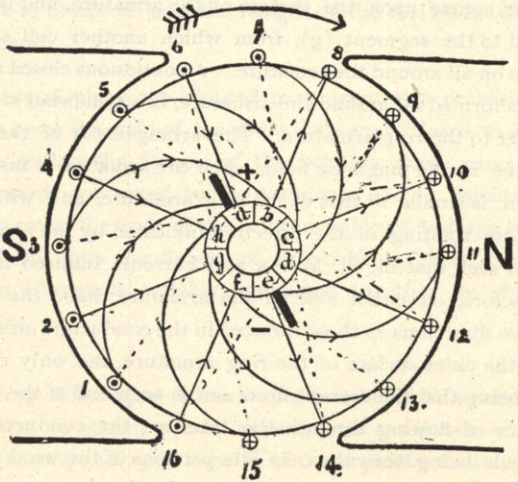


FIG. 128.

WINDING OF ARMATURES.

The manner in which the individual loops or coils are arranged will be rendered clear by following the course of a single loop or coil upon the armature.

Starting from the commutator segment (a) upon which the positive brush is resting at the upper portion of the armature, the conductor proceeds up the face of the drum to b, thence along the top and across the back end to the lowest part of the drum, from whence it proceeds across the bottom of the drum to 15. From 15 the conductor is brought around the face of the drum and connected to the commutator section (h), next to the one from which it started.

Another coil starts from the segment (h) and follows a similar course upon the surface of the armature, and is connected to the segment (g), from which another coil starts, and so on all around the armature. A continuous closed spiral is thus formed all around the armature, in a somewhat similar manner to the ring armature. The arrangement of the line of force in the magnetic field, when the armature is inserted therein, is similar to that of the ring armature, and with the armature rotating in the direction indicated by the arrow, it will be seen that the E. M. F.s and currents induced in the conductors, on either side of the armature, have the same relative directions as those induced in the conductors arranged upon the outer surface of the ring armature, the only difference being that the current flows across each end of the drum in place of flowing through the interior; the conductors at the ends being thus the only idle portions of the winding in the drum armature.

WINDING OF FIELD MAGNETS.

Field Magnet Windings.—The insulated wires used for the excitation of the field magnets, not being subjected to any of the detrimental influences experienced by the armature conductors, are in most cases of solid copper. As a rule, the wires are wound upon insulated spools, which are afterwards slipped over the limbs of the magnet; in some cases, however, they are wound direct upon the core of the field magnet, this latter being previously insulated with vulcanized fibre or other insulating material.

In general, the wires used for the exciting coils of shunt wound dynamos are very thin; hence, when this is used for making connection to the terminals of the machine, it is very liable to break off near the flanges of the reel upon which it is wound.

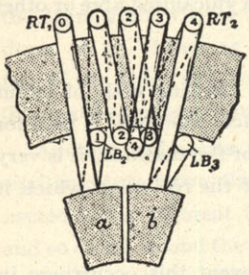
Several plans are adopted to prevent this occurring: in some cases the ends of the shunt coils are soldered to stouter wires within the flanges of the bobbins, these wires being afterwards connected to the terminals of the machine; in other cases, the ends of the coils are soldered to large terminals fixed upon the flanges of the bobbins, these terminals being afterwards suitably connected together by strips of copper.

Ring Windings.—When a ring core is to be wound, it is frequent to stencil upon the end faces a number of radial lines corresponding in breadth to the separate sections, so as to guide the winder in his work.

RING WINDINGS.

For ring-windings there is, in general, little trouble. Nevertheless, some care must be exercised. The separate "sections" of the coil are almost invariably wound on the cores separately, leaving the ends projecting, secured temporarily with string, and these ends subsequently connected together and to the commutator. An inexperienced workman may easily connect up wrongly; making a left-handed winding instead of a right-handed one, or *vice versâ*.

FIG. 129.



WINDING DIAGRAM. R ARMATURE.

Hence, it is well to provide him with some such working drawing as Fig. 129, which relates to a right-handed winding having four turns in each section. The wire marked "0" is the last or outer end of the section previous to that considered. This end will eventually be brought down to a bar *a* of the commutator, and from this bar will go out the beginning or left-bottom end, marked L B, of the section in question. Looking at this diagram the winder will see that the wire L B must pass under the core to the far end and then return over the top, thus making turn No. 1. It will then bend down to the right, be threaded through again, and make turn No. 2; again, and make turn No. 3; but as the inner space is narrower than the outer space, turn No. 4 will probably have to ride on, or partly bed between, the turns already wound. The right-top end, marked R T, will eventu-

ally be joined to bar *b* of the commutator. If the winder is shown that the right-top wire of one section joins the left-bottom turn of the next section at the commutator, he will have no excuse for mistakes. The winding of multipolar rings is absolutely similar, provided as many brushes are applied to the commutator as there are poles.

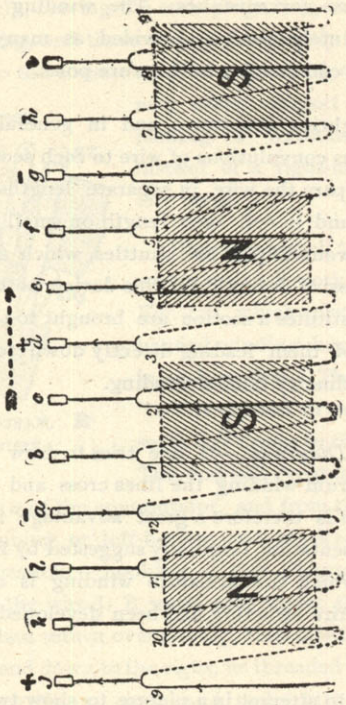
For arc-lighting armatures, and in general those which have numerous convulutions of wire to each section, it is convenient to prepare the wire in separate lengths sufficient for each section, and to coil each length on small shuttles each length being wound upon two shuttles, which are alternately used for successive layers. By this device both ends of the wire that constitutes a section are brought to the outside instead of one of them leading directly down to the bottom layer, as in ordinatry bobbin winding.

Winding Diagrams.—If one tries to draw all the connectors of a drum winding the lines cross and occasion confusion. There is therefore a great advantage in adopting a mode of representation, originally suggested by Herr Fritsche, of Berlin, in which the armature winding is considered as though the entire structure had been developed out on a flat surface.

If one was to attempt in a picture to show twenty or more conductors and their respective connections, the drawing would be unintelligible. Accordingly we have to imagine ourselves placed at the centre, and the panorama of the four

ARMATURE WINDINGS.

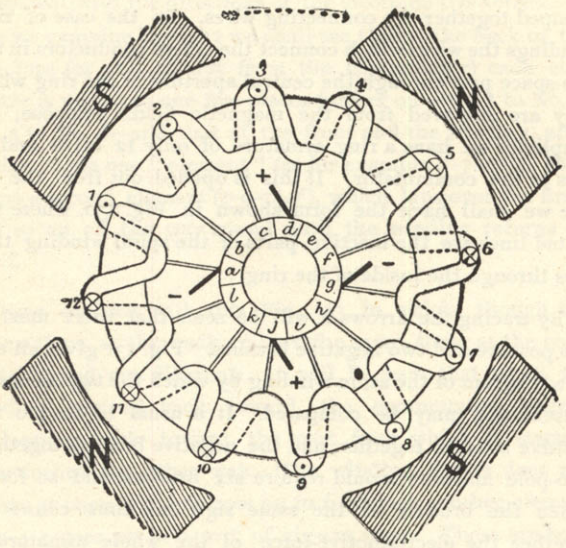
FIG. 130.



DEVELOPMENT OF WINDING FOR FOUR POLE MACHINE.

ARMATURE WINDINGS.

FIG. 131.



WINDING FOR FOUR POLE MAGNET TO CORRESPOND TO FIG. 130.

poles laid out flat, as in Fig. 130. It will be noticed that the faces of the N and S poles are shaded obliquely for distinction.

Now in an actual machine there are many armature conductors spaced symmetrically around, and these have to be grouped together by connecting wires. In the case of ring windings the wires which connect the active conductors in the gap-space pass through the central aperture in the ring when they are removed from the magnetic field. Suppose, for simplicity we have a ring armature of only 12 turns and 12 bars to the commutator. If this is opened out from the inside we shall have the form shown in Fig. 130, where the dotted lines are the inactive parts of the spiral winding that pass through the inside of the ring.

By tracing the arrows it will be seen that there must be two positive and two negative brushes. Fig. 131 gives an end view diagram of the same winding by which the two modes of presentation may be compared. It is usual to couple the positive brushes together, and the negative brushes together. A 6-pole machine would require six brushes, and so forth. When the brushes of the same sign are thus connected together the electromotive-force of the whole armature is simply that of any of the sets of coils from one + brush to the adjacent — brush.

Lap Winding and Wave Winding.—This distinction arises in the following manner. Since the conductors that are passing a north pole generate electromotive-forces in one

directions, and those that are passing a south pole generate electromotive-forces in the opposite direction, it is clear that a conductor in one of these groups ought to be connected to one in nearly a corresponding position in the other group, so that the current may flow down one and up the other in agreement with the directions of the electromotive-forces. If now we examine Fig. 132 we shall see that at the back of the armature (or end distant from the commutator) each conductor is united to one five places further on—No. 1 to No. 6, No. 3 to No. 8—and that at the front end the winding, after having made one "element" (as for example *d*–7–12–*e*), then forms a second element (*e*–9–14–*f*), which laps over the first; and so on all the way round until the winding returns on itself.

Now contrast with this Fig. 133, in which, though the connections at the back end are the same, those at the commutator end are different. It will be seen that when the winding returns back toward the commutator, instead of lapping back toward the part from which it started, it is turned the other way. The winding *d*–7–12 does not return at once to *e*, but goes on to *i*, whence another element *i*–17–4–*e* goes on in a sort of zig-zag wave. These are both drum windings, the corresponding winding tables being as shown in Figs. 134 and 135.

NOTE.—As each and every armature must needs have its own especial winding—based, of course, upon both experience and calculations, it will be understood that these few pages are given to explain the general practice—and in no other sense.

ARMATURE WINDINGS.

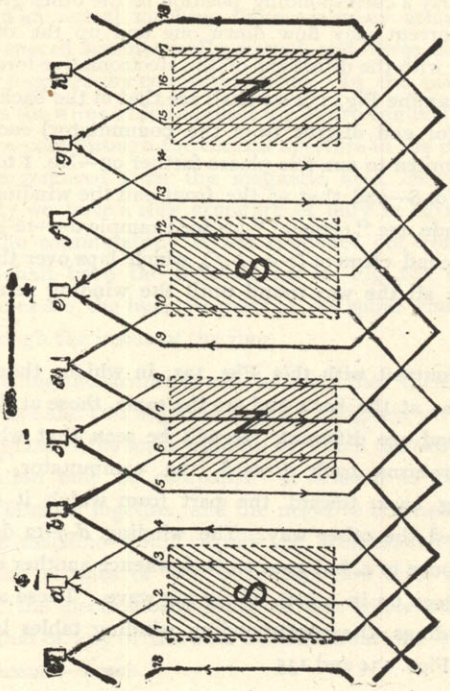
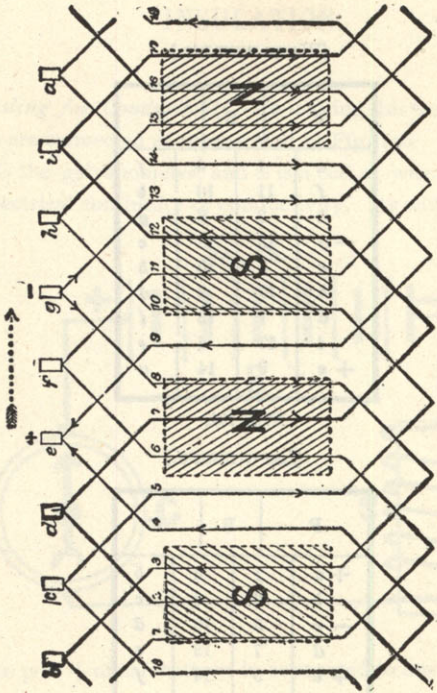


FIG. 132.

ARMATURE WINDINGS.



TYPICAL WAVE-WINDING.

FIG. 133.

ARMATURE WINDINGS.

Figs. 134 and 135 represent tables such as are furnished the practical workmen by the designers of the machines. These greatly facilitate the work and add accuracy to the building of the dynamo.

(WAVE-WINDING.)

F	B		F
a	1	6	*f*
f	11	16	*b*
b	3	8	*g*
— *g*	13	18	*c*
c	5	10	*h*
h	15	2	*d*
d	7	12	*i*
i	17	4	*e*
+ *e*	9	14	*a*

FIG. 134.

(LAP-WINDING.)

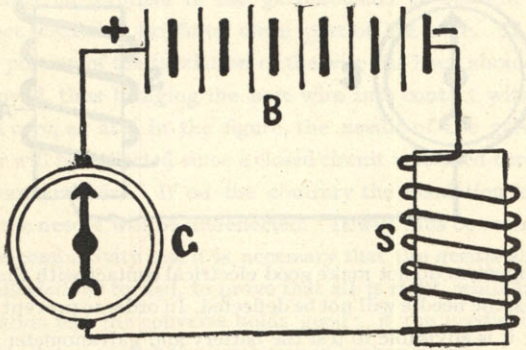
F	B		F
+ *a*	1	6	*b*
b	3	8	*c*
— *c*	5	10	*d*
d	7	12	*e*
+ *e*	9	14	*f*
f	11	16	*g*
— *g*	13	18	*h*
h	15	2	*i*
i	17	4	*a*

FIG. 135.

TESTING FOR CONDUCTIVITY AND INSULATION.

Testing for Conductivity.—In making this test, the instruments are connected as represented in Fig, 136. B is the battery, G the galvanometer, and S is a coil of wire being tested for electrical continuity or conductivity. As will be seen, the

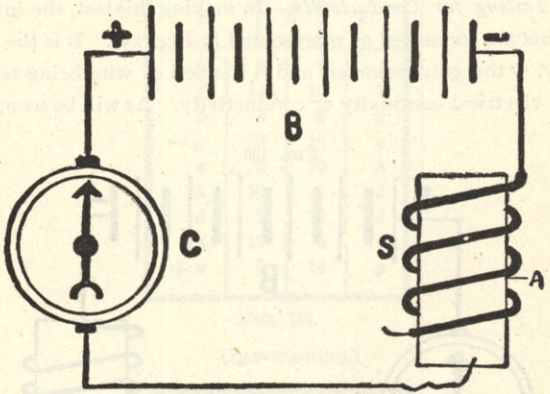
FIG. 136.



positive pole + of the battery is connected to one terminal of the galvanometer, and the other or negative pole is connected to one of the ends of the coil under test. The other terminal of the galvanometer is connected to the other end of the coil, If the connecting wires are making good electrical contact

with the respective terminals, and the wire of coil being tested is unbroken, the needle of the galvanometer will be deflected as soon as a closed circuit is made by the end of the coil coming into contact with the galvanometer terminal. If the wire of the coil is broken in some part or the ends of the con-

FIG. 137.

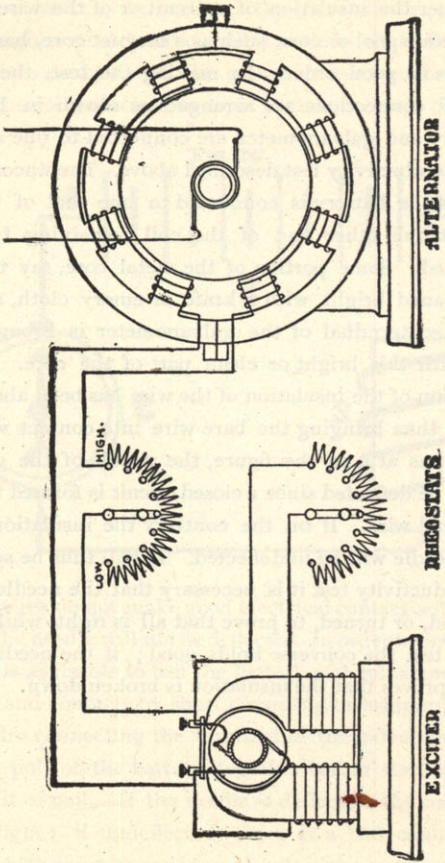


necting wires do not make good electrical contact with the terminals, the needle will not be deflected. In order to prevent mistakes, it is advisable to test the battery and galvanometer connections and contacts by short circuiting or bringing the ends of the wire connecting the terminal of the galvanometer and negative pole of the battery together before starting to test the circuit or coil. If the needle is deflected, the connections are all right; if undeflected, there is a bad contact somewhere, which must be made good before the test can proceed.

TESTING FOR CONDUCTIVITY.

Testing for Insulation.—The object of this test is to ascertain whether the insulation of a circuit or of the wire wound upon a metal spool or core, such as a magnet core, has broken down or is in good order. In making the test, the instruments and connections are arranged as shown in Fig. 137. The battery and galvanometer are connected to one another, as in the conductivity test described above. The unconnected terminal of the battery is connected to one end of the coil under test, the other end of the coil remaining free and unconnected. Some portion of the metal core, say the end, is then cleaned bright with a knife or emery cloth, and the unconnected terminal of the galvanometer is brought into contact with this bright or clean part of the core. If then some portion of the insulation of the wire has been abraded or destroyed, thus bringing the bare wire into contact with the metal core, as at A in the figure, the needle of the galvanometer will be deflected since a closed circuit is formed through the core and wire. If on the contrary the insulation is perfect, the needle will be undeflected. It will thus be seen that in the conductivity test it is necessary that the needle should be deflected, or turned, to prove that all is right, while in the insulation test the converse holds good; if the needle is deflected, it proves that the insulation is broken down.

FIG. 138.



THE ALTERNATOR.

A dynamo constructed without a commutator for making the current direct, produces an alternating current, and such a machine is called an alternator. A great many kinds of alternators have been constructed. They may be thus classified:

1. Those with a stationary field magnet and rotating armature.

2. Those with rotating field magnet and stationary armature.

3. Those with both field magnet and armature part stationary.

In the latter class, the amount of magnetic induction from the armature to the field is caused to vary or alternate in direction by the revolution of appropriate pieces of iron called inductors. Still another division rests on whether they give one simple alternating current, a two-phase current, or whether they give multiple currents.

In alternate-current working machines, the current is rapidly reversed, rising and falling in a succession of impulses or waves. Electricity is, in fact, oscillating backwards and

forwards through the line with enormous rapidity, under the influence of a rapidly-reversing electromotive-force.

The adjectives alternate, oscillatory, periodic, undulatory and harmonic have all been used to describe such currents; the term wave-currents is more apt.

The properties of alternate-curreuts differ somewhat from those of direct or continuous currents. They are affected not only by the resistance of the circuit but also by its inertia or self-induction, which diminishes the amplitude of the waves and retards their phase.

The alternating current enables us to take advantage of an effect called induction, which is only exerted when the current is suddenly broken or changed in direction.

The ordinary alternator has three or more pairs of poles instead of a single pair, and the armature carries as many coils as there are poles. These coils are coupled in series or in parallel so as to act as a single coil, the large number of poles increasing the number of alternations or cycles per second. Since alternating currents are used largely for lighting, it is necessary to have at least forty complete alternations per second in order to avoid flickering of the incandescent or arc lights.

NOTE.—The alternating current machine may be built to give directly a pressure up to 2,000 or 3,000 volts. and in certain types as high as 5,000 volts. If this is insufficient for the purpose, the voltage may be still further increased by the use of transformers.

THE ALTERNATOR.

Also, the transformers would have to be much larger if the frequency of alternations were less. For the systems in general use, sixteen thousand single alternations (eight thousand complete alternations or cycles) per second have been adopted as giving the most desirable frequency, the recent tendency being to reduce this to a considerably lower number. With a single coil armature revolving in a two-pole field, this would involve excessively high speed, hence the necessity for the multipolar field.

Multiphased currents are two or more separate and distinct currents not differing in any way from the current derived from an ordinary "single phase" alternator. Their peculiarity lies, not in the nature of the currents themselves, but in the fact that they have different strengths at a given instant of time.

In the two-phased system, for instance, when one of the currents is at zero value, the other has its maximum value, or the currents are displaced *in phase*, whence the expression two-phased.

If two identical simple alternators have their armature shafts coupled in such a manner, but when a given armature coil on one is directly under a field pole, the corresponding coil on the other is midway between two poles of its field, the two currents generated will differ in phase by a half-alternation, and will be two-phased currents; similarly, three-phased currents could be generated by coupling the armatures of three simple alternators so that the corresponding coils on each are equally "staggered" with respect to each other.

THE ALTERNATOR.

By the introduction of what is known as the multi-phase systems all difficulties have been overcome and alternating current motors are now manufactured which are equal to the best direct current motors in efficiency and starting torque, and which have the additional advantage of having no commutator or moving contacts of any kind.

Two-phase and three-phase currents differ in this respect; the two-phase system requires four wires to connect the generators with the motors and their action is that of two distinct and separate circuits through which are passing simple alternating currents of electricity which act upon the revolving part of the motor like the two cranks on a cross connected engine at right angles to one another, or one 90 degrees in advance of the other.

The three-phase method of employing the alternating current requires only three wires and for transmitting electrical energy in large amounts long distances for power purposes, it is an ideal system.

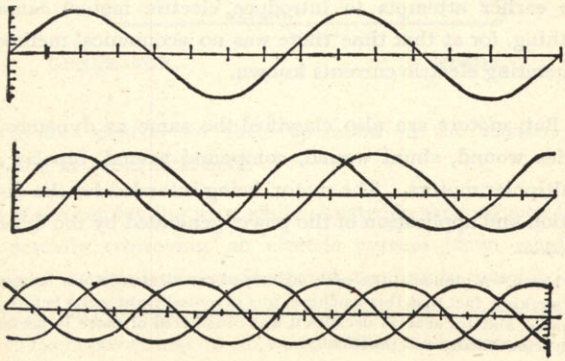
The Monocyclic System.—The "monocyclic" system is that in which three wires are used, but the main or energy current is conveyed by two of the wires, while the third one serves as an auxilliary and is necessary for starting the motor. The motors are of the class called "induction motors" from the fact that the current in the armature or revolving part is induced by an alternating current in a stationary coil outside of the armature and at an angle to the field, instead of being con-

NOTE.—The Fig. on the next page is intended to show the "wave motion" of the different alternations.

ducted into the armature through sliding contacts as in the more familiar direct current motor.

Motors constructed upon this principle have the advantage of great starting power, and are able to stand temporary overloads without damage. They can be made smaller than the direct current type, are cylindrical in shape and adapted to be put in any position. They are almost as simple as a grindstone, and having self-oiling bearings, require scarcely any attention at all.

The monocyclic in its broadest sense is a combination of the single-phase and three-phase systems. Three-phase currents are produced from single-phase currents by means of a specially wound armature which may be operated as a motor-generator at the point where energy for motors is to be distributed, or the main generator may be provided with a special armature arranged to produce the necessary difference of phase between the ordinary two-wire circuit and a third wire.



MOTORS.

Very nearly all that has been said upon the subject of dynamos applies to the motor and needs not to be repeated. Motors are, however, divided into two general classes:

1. Those for use with continuous currents.

2. Those for use with alternating currents.

The real development of the motor as a transmission of power machine came after the commercial introduction of Gramme's dynamos in 1871, as engineers began to understand how two of these machines could be used—one as generator, the other as motor—to transmit power through a line. All the earlier attempts to introduce electric motors came to nothing, for at that time there was no economical method of generating electric currents known.

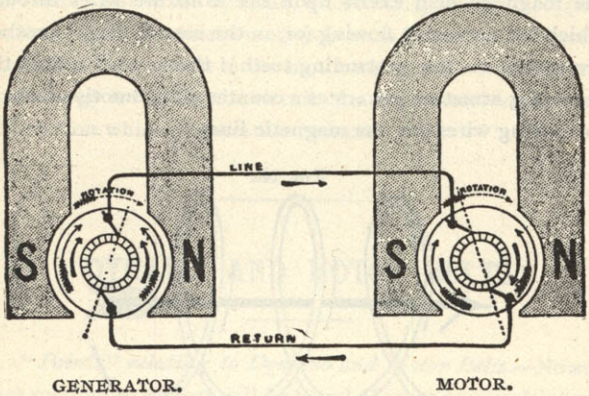
But, motors are also classified the same as dynamos, as series wound, shunt wound, compound wound, bipolar and multipolar motors. The motor being intended for the distribution and application of the power generated by the dynamo

NOTE.—A glance at the early history of the electric motor brings out the striking fact that this machine was invented eight years before the dynamo, and for several decades it was considered of more importance, both scientifically and practically.

is usually a much smaller machine—thus a dynamo of 1,000 horse power will furnish the necessary force for nine or ten 100 horse power motors.

In construction, the dynamo and motors are essentially the same, but in their action are exactly the reverse.

FIG. 139.



GENERATOR. MOTOR.

Motors depend for their operation on the tendency to motion in a magnetic field.

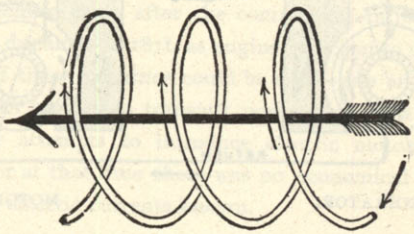
If the conducting wire, while situated in the magnetic field, is actually conveying an electric current (from whatever source) it experiences a side thrust, tending to move it forcibly, parallel to itself, across the magnetic lines and so enables it to exert power and to do work. This is illustrated in Fig.

140, where the small arrows exhibit the movement of the current and the large arrow the resulting push or magnetic force.

This action is the principle of the dynamo used as a motor.

Two points are vital to the right understanding of the action of electric motors: (1) the propelling drag, (2) the counter electromotive-force. The first is that the real driving-force which propels the revolving armature is the drag which the magnetic field exerts upon the armature wires through which the current is flowing (or, in the case of deeply-toothed armatures, on the protruding teeth): the second is that the revolving armature generates a counter electromotive force as its moving wires cut the magnetic lines.

FIG. 140.



The Propelling Drag.—In a generator the drag acts in a direction which opposes the rotation, and is, in fact, a counter-force or reaction against the driving force. In a motor the drag is the driving-force, and produces the rotation.

The Counter Electromotive-force.—Let it be remembered that wherever in an electric circuit, current flows through some portion of the circuit in which there is an electromotive

force, the current will there either receive or give up energy according to whether the electromotive-force acts *with* the current or *against* it. This will be made clearer by Fig. 139, representing a circuit in which there are a dynamo and a motor. Each is rotating right-handedly, and therefore generates an electromotive-force tending upwards from the lower brush to the higher. In each case the upper brush is the positive one. But in the dynamo, where energy is being supplied to the circuit, the electromotive-force is in the same direction as the current; whilst in the motor where work is being done, and energy is leaving the circuit, the electromotive-force is in a direction which opposes the current.

DYNAMO AND MOTOR BELTS.

"Points" relating to Dynamo and Motor Belts.—No subject relating to motors will be found of more practical interest than the following:

1. Dynamo belts should make a straight run through the air and over the pulleys without wabbling; they should maintain an even and perfect contact with that part of the pulley with which they come in contact. In order to do this they should be kept soft, pliable, and have no abrasions or rough places—the belt should be first-class—as near perfection as possible, for they must do their work so the light burns with-

DYNAMO AND MOTOR BELTS.

out flicker. When belt fasteners give way there is too much strain upon belt. The greatest amount of slack in a belt is found when it leaves the driving pulley, hence the tightener should be near the driving pulley, as it takes up the slack, prevents vibration and diminishes strain on belts and bearings. More than 110° of heat is injurious to belts.

2. The double belt should always run with the splices, and not against them. One-quarter turned belts should be made of two-ply leather, so as to avoid so much side strain. Slow-motion belts should be made of two-ply leather, as they receive hard labor and strains.

3. The electric generators of the alternating system require special belts, as they are run at great velocity. Belts for the alternating system should be endless, perfectly smooth, even in texture and thickness. If too much power is added to the sticking or adhesive qualities of a belt the friction will cause loss.

4. Friction is greatest when the pulleys are covered with leather. Friction depends upon pressure, but adhesion depends upon the surface contact; for instance, two square feet of adhesion will hold twice as much as one square foot, hence, the more a belt adheres to pulley surface without straining, through too much tightening, the better the driving power. Wet days produce slipping because the leather absorbs dampness.

5. A leather-covered pulley will produce more resistance than polished or rough iron ones. A good belt dressing makes a smooth, resisting surface, and as it contains no oils, which

create a slippery surface to belts, it increases belt adhesion. The friction of leather upon leather is five times greater than leather upon iron.

6. Moisture and water distend the fibres, change the properties of the tanner's grease and softening compounds. Repeated saturation and drying will soon destroy leather. Leather well filled with tanner's grease or animal oil, if allowed to hang in a warm room for several months without handling, will dry out, become harsh, and will readily crack.

7. Many things have been used to make belts stick to the pulleys, some of considerable value. A careful study of all the parts that work together is required in order to get full power transmission. Suitable belt dressing will overcome many serious questions that arise, but it must be properly applied.

8. A running belt is stretched and relaxed at different times, and unless there is perfect elasticity in all its parts there will not be uniform distension. Whatever relieves the strain upon belts prolong their life. There should be 25 per cent. margin allowed for adhesion before a belt begins to slip.

9. The adhesion between the surface of belt and pulley must produce more friction than the pull or tension. When great tension or stretching is required it evidences the fact that the belt is not properly proportioned, or that it is oil soaked and there is too much oil on the pulleys.

10. An endless belt will always give the best results, as lacing produces a momentary flicker in the lights at each revolution.

ELECTRICAL POWER TRANSMISSION.

As compared to any other known method of transmitting power it may be said that electricity is an ideal agent, for as it has been well said—

FIG. 144.

LINE WORK.

Electricity never stretches, never breaks, weighs nothing, can be subdivided indefinitely with great ease, can turn corners without loss. It can transmit large amounts of energy at pressures easily controlled along wires of moderate size, and it never freezes. Its loss by friction is comparatively insignificant, and its other losses in comparison with every other known agent are almost nothing.

The period of planning the schemes of transmission, of designing the dynamos, and of construction is now ended and all criticism as to dividends on the cost of electric works has been swept away by the results achieved. The efficiency of each type of machine and system is now greater than has been attained before, and definite results are assured.

ELECTRIC POWER TRANSMISSION.

A system for the transmission of electric energy embraces: First, a conducting circuit between the two stations. Second, a battery or dynamo arranged to furnish the current. Third, the motor for changing the electric back into mechanical energy.

Electric transmission can be used to advantage with standard forms of machines as follows:

First, where a large waterpower is available at a considerable distance from the mill which is in need of more power than can be obtained from the water privilege at the mill itself.

Second, where owing to the separation of mill buildings, or peculiar local requirements, it is desired to transmit power

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NOTE.—The waters of the American River, which have been running to waste, are now utilized for lighting Sacramento's streets, propelling her cars, operating her factories and cooking the food of her citizens. Years have been spent on the work here. An immense masonry dam was thrown across the American River at Folsom, California, creating a reservoir three miles long and furnishing a flow of 85,000 cubic feet a minute. The water, after passing through four horizontal shaft double turbine wheels, is used for irrigation purposes, and 300,000 acres of land will be supplied. The turbine wheels are 30 inches in diameter, and under a head of 55 feet develop 1,300 horsepower each. The shafts of the wheels are coupled direct to the shafts of four three-phase alternating current generators of the General Electric type, each capable of developing 1,000 horse-power. These dynamos weigh about forty tons each. The electric current is passed through "step-up" or raising transformers which raise the voltage to 16,000 volts, and it is then transmitted by overhead copper wires to this city.

Two separate lines have been built as a precaution against accident or shutdowns for repairs. One line will always be held in reserve. It is calculated that 50 per cent of the electric power generated at Folsom will be transmitted twenty-four miles to Sacramento.

further than can be done by belting in order to avoid the instalment of individual steam plants in each building.

Third, where small water privileges are available at various points on a stream, but in order to become useful the power must be concentrated at one point without too great expense for maintenance and operation of the individual parts of the system.

Fourth, where for various reasons in securing a mill site it is desirable to locate at a considerable distance from the source of power on account of the fact that the land immediately adjacent to the privilege is not suitable for location.

Fifth, where for special reasons it is important to do away with shafting throughout the mill.

Electric motors in the machine shop work so satisfactorily for power transmission and effect such evident savings in the cost of manufacturing that they are utilized in many ways. The motors used average about 3 H. P. and are connected by insulated wires strung to switches located at convenient points about the shop. No pains are taken to fasten the motors while they are at work, as their own weight is amply sufficient to hold them in position and keep the belt tight.

The great convenience of moving tools and placing them in any desired position is a great advantage of the new system.

NOTE.—The great adaptability of this system was well shown in the case of a factory which was almost completely destroyed by fire, nevertheless a few uninjured tools in a remote end of the building were operated successfully by means of electric motors within two days after the fire.

ELECTRIC POWER TRANSMISSION.

Practically the only objection which can be urged against the electric system of transmission is the fact that the first cost of installation is greater than with ordinary belting and shafting, but even this is questionable, since while it might seem that the electric system would actually consume more power than the ordinary plan since it involves two transformations of energy. In most cases, however, if the power has to be distributed to a number of machines, particularly if they are located at any distance from the engine, the loss of power is less with electric transmission. This is explained by the high efficiency of the dynamo and motor compared with the low efficiency of belt transmission as ordinarily practiced. Perhaps the greatest saving, however, of the electric system is due to the fact that the consumption of energy entirely ceases when the tool stops. This stoppage in the case of the busiest tools amounts to at least 25 per cent. of the nominal working hours throughout the year and with large or special tools which are not used so steadily, the stoppage is often as high as 50 to 75 per cent. since there are many whole days when they are not used at all.

Wherever electric motors can be substituted for a number of small engines scattered about, the saving in power is very great not only because of the low efficiency of small steam engines, but also by the avoidance of condensation in long steam pipes.

Perhaps the most important advantage gained by the electric system is in the increased output since the cost of power is a very small item. This increased output is secured

by the greater convenience and promptness in starting and stopping as well as in regulating the speed of the machinery. The workman can, for example, temporarily increase the speed, when conditions are favorable, thereby saving considerable time.

The ordinary type of motor used in factories is the plain shunt wound machine fed with constant potential current. The motor is started and varied in speed by means of a rheostat in the armature circuit. This simple arrangement answers very well in most cases, but for variable speed between wide limits a series wound motor controlled by a rheostat as in electric railway practice may be preferable. In other cases some special method of regulation such as the Leonard system, or the "boost and retard" plan may be adopted.

Electrical Transmission in Mines.—It is predicted that the day is not far distant when every large mine in the country will have adopted electric power, and that such adoption, in view of superior advantages for continuous service, as shown in the record of the Mammoth mine outfit, will result in the more general use of convenient water power.

The utilization of water power electrically transmitted for mine operation is becoming more popular among mining men, as each installation demonstrates not only the feasibility of the system but also the economy which every such installation shows when compared with pre-existing systems which it displaces or which are in similar operation elsewhere.

ELECTRIC POWER TRANSMISSION.

Long Distance Electrical Transmission.—In a general way, at the usual price of coal, the transmission of power from cheap water power, up to ten or fifteen miles, will nearly always pay, if the amount be reasonably great, a few hundred or a thousand horse power; while the current can readily be transmitted over enormously great distances—several hundred miles—practically speaking, such transmissions will probably be exceedingly rare for many years to come.

Admitting that power can be transmitted satisfactorily, the next point is as to the economy of this electric transmission. In the cost of a water privilege at a distance, where the problem is to transmit power in bulk for a few thousand feet or more, the practical question is simply one of cost of power delivered on the ground by steam. The cost of power delivered to the motors, of course, depends upon the value of the water privilege, its cost to electrical apparatus and local conditions.

NOTE.—The project is now discussed in England to supply electric power from central stations built in the centre of the coal fields and transmit it to the great industrial centres, including London, where transmitting and storage stations could be erected. The electric energy could be sold to the different distributing companies at a little over two cents per kw hour and to the small factory owner for about $25 per 3,000 working hours for one H. P.; in London this costs at present about twice as much; the system enables valuable chemical constituents to be recovered from the coal, which at present cannot be done in the smal steam power plants; one of these constituents is sulphate of ammonia; it is estimated that one H. P. hour can be obtained for ¾ pound of coal, the average consumption at present being 5 pounds; the loss in transmission from the coal fields to London is about 33 per cent.; for transmitting 10,000 H. P., three bare conductors for the positive and three for the negative would be used and run on oil insulators; 30,000 volts are to be used.

ELECTRIC POWER TRANSMISSION.

As regards the difficulties which have to be encountered in electrical power transmission, the principal ones centre about the transmission line. Speaking from an electrical standpoint, it is sometimes difficult to get and maintain insulation against the voltages put to use for long distance work. Physically the maintenance and guarding of a long line against accidents, or malicious injury, is not altogether easy to be paid. The difficulties include such things as severe storms, which tear down the line, or blow down trees across it, accidental or malicious breaking of insulators and the like, to say nothing of the ordinary wear and tear to which overhead lines are subjected. Quite aside from such special causes of damage, the generation and utilization of power is all clear sailing.

Economy of Electric Locomotives.—Under certain conditions no doubt exists as to the economy of electrical appliances. In the saving in repairs it is stated on the authority of Siemens that the electric locomotives on the underground railway in London ran 60,000 miles without needing repairs of any kind. In the wear of tracks, in lighter road-beds and bridges and in steeper grades, the economies from this standpoint are beyond peradventure. The building of electric power stations of smaller capacity than the aggregate capacity

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NOTE.—5,000, 10,000 or 15,000 volts is within the range of fair practicability if the climatic conditions are favorable. I would not hesitate to make it 30,000, 40,000 or 50,000 volts, in a climate like that of some parts of Mexico, while I would shun half of this, in a stormy or damp climate.—Prof. Bell.

of locomotives, and the saving in coal consumption by working steam economically in large cylinders are placed in the favor of electric traction.

These remarks apply very nearly to all forms of electric transmission.

The Niagara Falls Power Plant.—No enterprise of modern times has attracted greater attention from the engineers of the world and public in general than the work which was undertaken some years ago by the Niagara Falls Power Company for the utilization of a portion of the power of the Niagara Falls through electric-motors operated by turbine water wheels.

About 275,000 cubic feet of water pass over the falls each second, falling from the crest of the falls 165 feet, furnishing, as it has been estimated, not less than seven million of horse power.

The surface canal starts from a point about one and one-half miles above the falls and runs inland 1,700 feet, with a depth of 12 feet, the main tunnel being 7,000 feet long, 19 feet wide and 21 feet high. This artificial waterway has a capacity sufficient to develop 100,000 horse-power.

This great work is under construction in what are called "units" of 5,000 electric horse-power, several of which are in most successful operation.

volts, and the secondary coil has one-tenth as many turns, the pressure in the secondary will be 100 volts.

THE DYNAMOTOR.

A dynamotor is an electrical apparatus in which two machines, a dynamo and a motor, are placed on the same shaft, one of the machines receiving current, and the other generating current, usually of a different voltage.

In one form two armatures are mounted on one shaft in a single field or in separate fields; one is a motor armature driven by the original current; the other generates new current. This is a "motor-dynamo," and it can transform continuous currents up or down.

Continuous current transformers have attained an efficiency of 83 per cent. at full load.

Another form of dynamotor is called the continuous alternating transformer. This is arranged so as to change a continuous into an alternating current or the reverse.

As the driven and driving parts of the dynamotor are contained in one rotating part, their friction is very slight.

NOTE.—The long distance transmission lines for a certain railway are connected to step-down transformers, transforming the current from 6,000 volts on the line to 400 volts at the secondaries. The secondaries are connected to the three collector rings on one side, and the current is thus brought into the armature of the rotary converter or dynamotor. The alternating current at 400 volts is then converted in this machine into direct current at 500 volts at no load and 550 volts at full load delivered from the commutator side. This is given as example of the ultility of the dynamotor.

TRANSFORMERS.

For the sake of economizing the cost of the metallic conductors, distribution of the electric current is effected at a high electric pressure from the central generators, and is re-

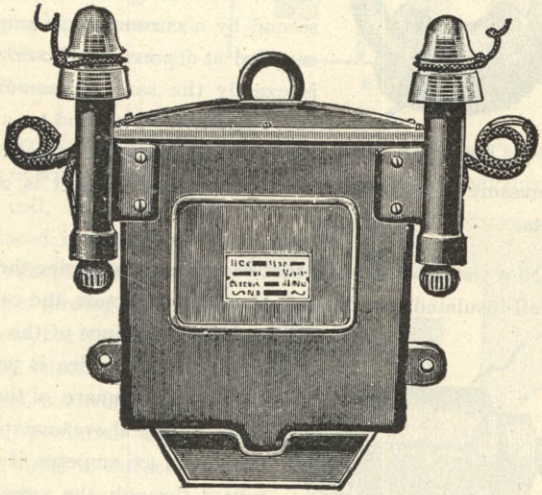


FIG. 142.

ceived at different points by apparatus known as *transformers*, which transform the electric energy supplied to them, and give it out again at a lower pressure.

TRANSFORMERS.

To comprehend fully the bearing of the matter, it must be remembered that the energy supplied per second is the product of two factors, the current and the pressure at which that current is supplied; the magnitudes of the two factors may vary, but the value of the power supplied depends only on the product of the two; for example, the energy furnished per second by a current of 10 amperes supplied at a pressure of 2000 volts is exactly the same in amount as that furnished per second by a current of 400 amperes supplied at a pressure of 50 volts; in each case the product is 20,000 watts.

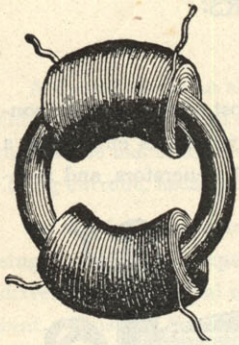


FIG. 143.

Now the loss of energy that occurs in transmission through a well-insulated wire depends also on two factors, the current and the resistance of the wire, and in a given wire is proportional to the square of the current. In the above example the current of 400 amperes, if transmitted through the same wire as the 10-ampere current, would, because it is forty times as great, waste sixteen hundred times as much energy in heating the wire. Or, to put it the other way round, for the same

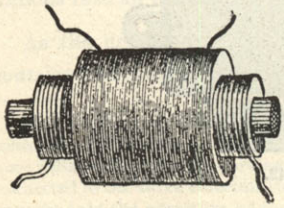


FIG. 144.

loss of energy one may use, to carry the 10-ampere current at 2000 volts, a wire having only $\frac{1}{1600}$th of the sectional area of the wire used for the 400-ampere current at 50 volts. The cost of copper conductors for the distributing lines is therefore very greatly economized by employing high pressures for distribution of small currents.

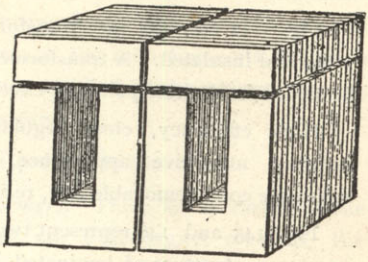


FIG. 145.

Operation of the Transformer.—If we wind two separate coils of wire on an iron bar, and pass a direct current through one coil, no effect is produced in the other coil except at the moment of turning on the current, but if an alternating current is used instead, a current is at once produced and maintained in the second coil. By a very simple law the pressure or voltage of the two coils are in proportion to the number of turns in each. Thus, if the primary coil is supplied with current of 1,000 volts, and the secondary coil has one-tenth as many turns, the pressure in the secondary will be 100 volts.

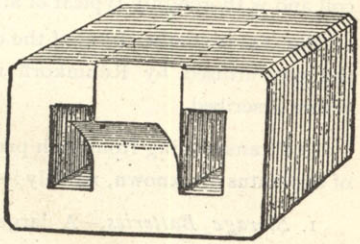


FIG. 146.

TRANSFORMERS.

By the proper proportion of the primary and secondary coils, the voltage may be raised to any pressure which can be safely transmitted.

Fig. 142 exhibits the transformer with its connecting wires and insulated. A transformer of the latest pattern may be said to have these points of excellence :

High efficiency, close regulation, small leakage, quiet running, attractive appearance, convenient arrangement, separable core, removable coil, reliable fuse device.

Fig. 145 and 146 represent two methods of procuring the necessary structure of laminated iron, the parts in this case being stamped from sheet iron. This is done to secure good magnetic circuit with ample ventilation.

Fig. 143 is a representation of Farraday's first induction coil and is thoroughly typical of all transformers.

Fig. 144 is another form of the cylindrical transformer and the one utilized by Ruhmkorff is his special machine elsewhere described.

For transforming from high pressures to low, several kinds of apparatus are known, namely :—

1. *Storage Batteries.*—A large number of these to be charged in series at a high potential ; the series afterwards divided up or rearanged so as to discharge larger currents at lower pressure. This system is applicable to direct-current working only, not to alternate currents, and has the advantage of storing the consumer's supply. These will be treated on in a separate section.

TRANSFORMERS.

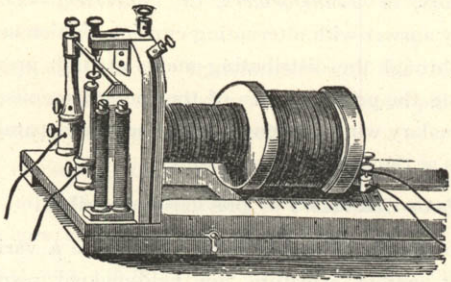
2. *Induction Coils*, also called for this purpose *Secondary Generators*, or *Transformers*, or *Converters*.—This system will only answer with alternating currents, which being transmitted through the distributing maids at high pressure, and traversing the primary wires of the induction-coils, set up in the secondary wires currents which feed the separate circuits of lamps at the desired low pressure.

3. *Motor-Generators* as previously described.

4. *Commuting-Transformers*.—These are a variety of the last, but neither armature nor field-magnet revolves, the polarity of the magnetic circuit being caused to vary by special commutators.

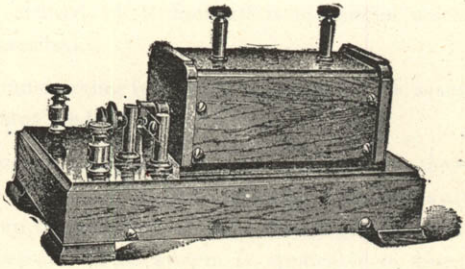
5. *Condensers*.—It is theoretically possible to employ condensers for transforming alternate currents, but their use is not yet practical.

FIG. 147.



INDUCTION COIL.

FIG. 148.



RUHMKORFF COIL.

THE CONDENSER.

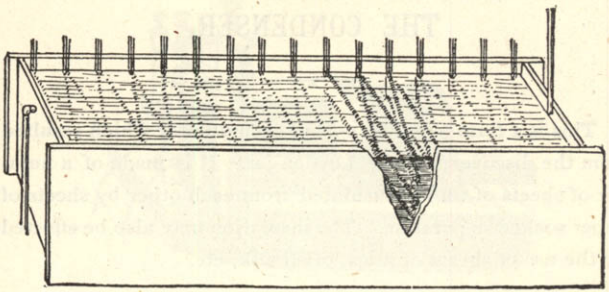
This is a form (see Fig. 150) of accumulator which resulted from the discovery of the Leyden-jar. It is made of a number of sheets of tin foil insulated from each other by sheets of paper soaked in parafine. The insulation may also be effected by the use of sheets of mica, oiled silk, etc.

The telegraphic condenser consists of a box packed full of sheets of tin foil, the alternate sheets of which are connected with each other and each set has its own binding post.

The tin foil is used in condensers because it is the cheapest for any two conductors which are near together and insulated from each other, acts as a condenser. The iron frame of a dynamo or motor and the wire wound upon the fields and armature act as the two surfaces of a condenser, and one may sometimes get a severe shock by touching both at the same time. A long insulated wire buried in the earth or in the water forms a condenser on account of the surface of the wire and the surface of water or earth outside being so large and so close together.

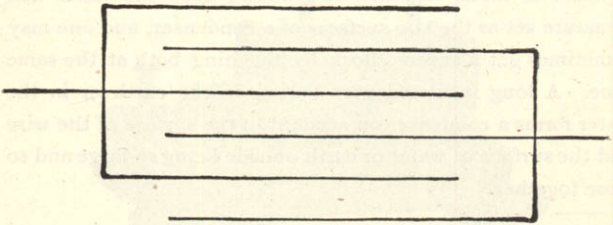
NOTE.—The object of the condenser is, firstly, to make the break of circuit more sudden by preventing the spark due to self-induction in the primary circuit from leaping across the interrupter; and, secondly, to store up the electricity of this self-induced extra-current at break for a brief instant, and then discharge it back through the primary coil so as to augment the induced direct electromotive-force in the secondary coil.

FIG. 149.



ADJUSTABLE WATER RESISTANCE.

FIG. 150.



CONDENSER.

INDUCTION COILS.

An induction coil comprises three principal parts—the core, the primary coil, and the secondary coil.

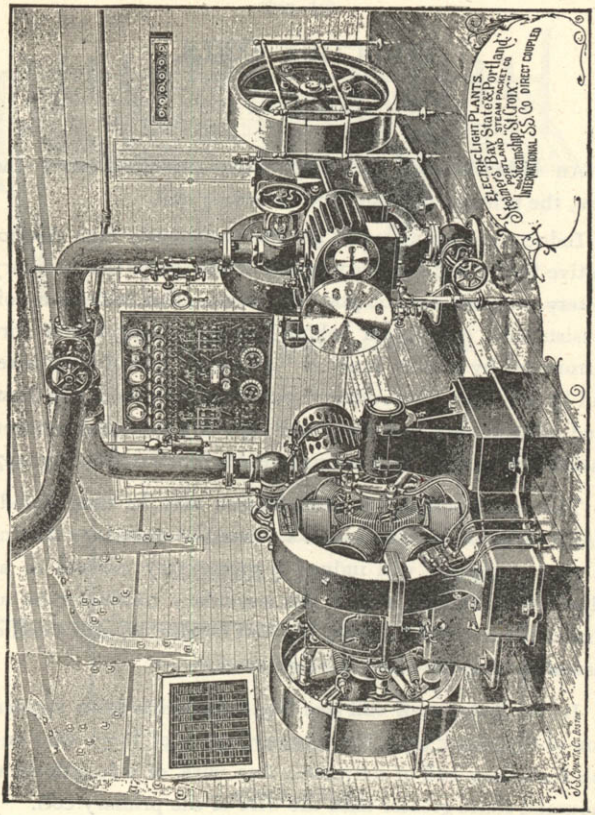
Induced currents have in general enormously high electro-motive-forces, and are able to spark across spaces that ordinary battery currents cannot possibly cross. The induction coil consists of a cylindrical bobbin having a central iron core surrounded by a short inner or "primary" coil of stout wire, and by an outer "secondary" coil consisting of many thousand turns of very fine wire, very carefully insulated between its different parts. This arrangement is illustrated in Fig. 147.

The fundamental law of induction may be thus stated: "Any variation or cessation of a current of electricity flowing in one conductor will induce a momentary current in an adjacent conductor; and if the secondary conductor be an insulated wire coiled around the first conductor, also a coil of insulated wire, the effect is heightened."

In the Ruhmkorff coil (see Fig. 148) which is an application of the above laws, the primary coil is of large wire and the secondary coil of extremely fine wire, of a length many thousand times greater than the wire of the primary coil.

NOTE.—Fig. 149 represents an adjustable water resistance, available for use as an artificial load either for arc-lighting machines or the alternators.

FIG. 151.


ELECTRIC LIGHT PLANTS
Bay State & Portland
Steamers, Inland Steam Packet Co
Mississippi River Steamboats
INTERNATIONAL S.S. Co DIRECT COMPOUND

ELECTRIC LIGHT PLANT, STEAMER "BAY STATE."

ELECTRIC LIGHTING.

There are two systems of electric lighting in common use:

1. Arc Lighting.

2. Incandescent Lighting.

FIG. 152.

Candle Power, by which these are measured, is the amount of light given by the standard candle. The legal English and standard American candle is a sperm candle burning "two grains a minute." It should have burned some ten minutes before use and the wick should be bent over and have a red tip. Otherwise its readings or indications are useless. A "sixteen candle-power" lamp means a lamp giving the light of sixteen candles. The candle-power is a universal unit of illuminating power.

NOTE.—According to some recent experiments made by the Government of the United States, a 1 candle-power white light is visible at a distance a little more than a mile, one of 3 candle-power is visible at two miles; on an exceptionally clear night a white light of 3.2 candle-power was readily distinguished at three miles; one of 5.6 candle-power at four miles, and one of 12.2 candle-power at five miles; a green or red 2 candle-power light was visible at one mile, 15 candle-power at two miles, 51 candle-power at three miles and 106 candle-power at four miles.

ELECTRIC LIGHTING.

The Arc-light.—If two pointed pieces of carbon are joined by wires to the terminals of a generator of electric currents, and are brought into contact for a moment and then drawn apart to a short distance, a kind of electric flame called the arc or the voltaic arc is produced between the points of carbon, and a brilliant light is emitted by the white hot points of the carbon electrodes.

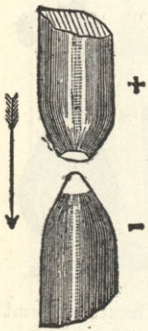


FIG. 153.

This phenomenon was first noticed by Humphrey Davy in 1800, and its explanation appears to be the following: Before contact the difference of potential between the points is insufficient to permit a spark to leap across even $\frac{1}{10000}$ of an inch of air-space, but when the carbons are made to touch, a current is established. On separating the carbons the momentary extra-current due to self-induction of the circuit, which possesses a high electromotive-force, can leap the short distance, and in doing so volatilizes a small quantity of carbon between the points. Carbon vapor being a partial conductor allows the current to continue to flow across the gap, provided it be not too wide; but as the carbon vapor has a very high resistance, it becomes intensely heated by the passage of the current, and the carbon points also grow hot. Since, however, solid matter is a better radiator than gaseous matter, the carbon points emit far more light than the arc itself, though they are not so hot. In the arc the most infusible substances, such as flint and diamond, melt;

and metals such as gold and platinum are even vaporized readily in its intense heat.

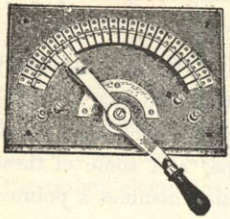
When the arc is produced in the air the carbons slowly burn away by oxidization. It is observed, also, that particles of carbon are torn away from the + electrode, which becomes hollowed out to a cup-shape, and some of these are deposited on the — electrode, which assumes a pointed form.

In the alternating current arc lamp, since the current flows alternately in each direction, the carbons burn away with uniform rapidity and the ends assume about the same form. The light will be thrown up and then down as the direction of the current changes, and for this reason reflectors are placed above the arc to catch the upward rays.

The familiar prism and spectrum experiment shows that all ordinary "white" light is made up of colors, shades of red, yellow, green and blue. The quality of any light will depend upon both the presence and intensity of these component color-groups. When the incandescent lamp burns low the red and yellow rays are mainly present; as it grows hotter the greens and blues are added, until, when all are present in correct proportion, the light is pure white. Analysis of the components of ordinary lights shows that the candle and oil flames are made up mainly of red and yellow, with some green and faint blue rays.

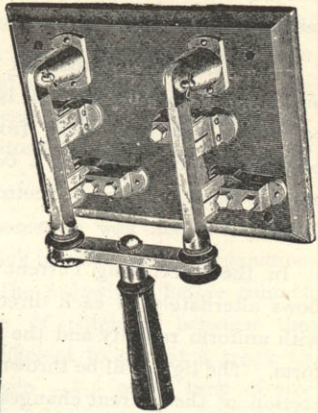
The two pencils in the modern arc lamp are separated by a distance of from one-sixteenth to three-sixteenths of an

FIG. 154.



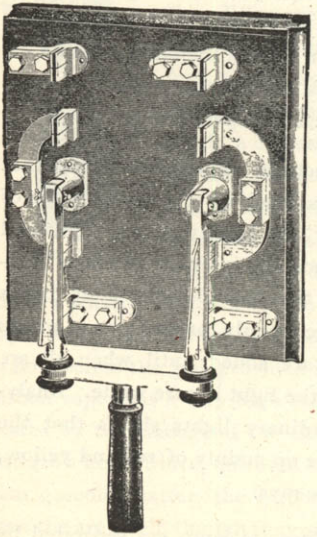
RHEOSTAT.

FIG. 155.



SINGLE KNIFE SWITCH.

FIG. 156.



DOUBLE KNIFE SWITCH.

inch. The electricity, in overcoming the resistance of this air gap, generates such an amount of heat that the tips are kept at a white glow. The carbon toward the positive pole of the machine will be found to be cone-shaped with a depression at the top, whence it derived the name "arc-light"—the crater in the cone assuming the form of

an arc or part of a circle. The other carbon will be found slightly rounded with a little pyramid just beneath the crater of the upper carbons. Under these conditions, it will be noticed that the positive carbon, or one nearest the positive brush of the dynamo, will burn away much faster than the other, and because the greater amount of light is desired below the lamp, the positive carbon is placed above the other.

Long before the incandescent electric light had been invented, the arc light made by an electric arc formed between

---

* NOTE.—It was about this time that popular explanations begun to be made of the nature and source of electricity; on the installation of a 4,000 candle light arc lamp, one man who had gathered a crowd around him thus proclaimed, calling attention to the solenoid at the top of the lamp: "That is the can that holds the oil," and, speaking of the side rod of the lamp, "That is the tube which conducts the oil from the can to the burner." This season also witnessed the introduction of the arc light into "Wannamaker's" at Philadelphia. One gentleman on that occasion looked the whole apparatus over very carefully, perhaps a half hour, sized it up, and then, pointing to the line wire, he said, "How large is the hole in that wire that the electricity flows through?" Another gentleman, one connected with a great manufacturing company, observed in complete silence the machine running for perhaps five minutes. Then he fully digested the whole thing, and was ready to tell all about it. He said, "The electricity in that thing is generated by that revolving business there, rubbing the air up against these iron blades (meaning the magnets), just as you get sparks when you rub a cat's back."

In the following year, 1879, the Cincinnati Exposition Buildings were lighted, and an expert from New York City was sent out to make matters go smooth, but one distressful night he failed to appear, and a self-examined engineer was put in charge, but the lamps would not "illumine"—so the next morning Mike was sent for. "Well, Mike, why didn't your light burn last night?" "Sure, sir, I don't know. I do be thrying to do me part; it's more than the full of a box of matches I spint a-thrying to light thim two black sticks, and dev'l a light could I get." The great pile of burnt matches under the lamp bore evidence of the truth of Mike's assertion.

FIG. 157.

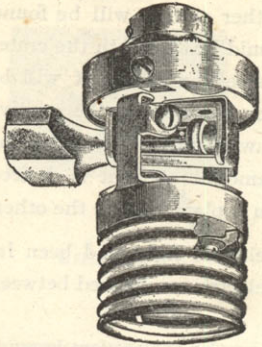
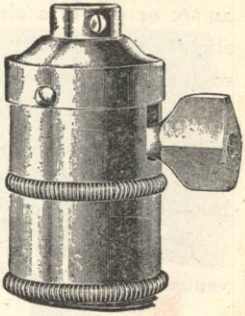
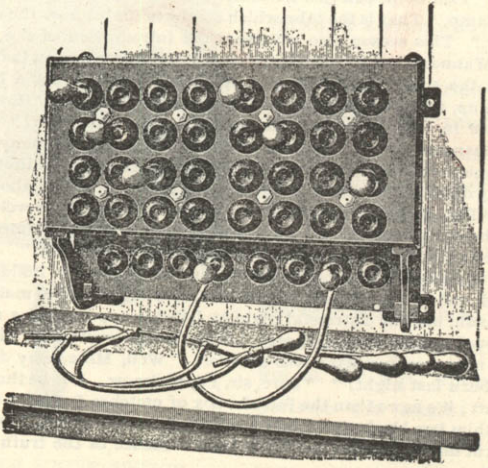


FIG. 158.



LAMP SOCKETS.

FIG. 159.



SWITCH BOARD.

the ends of two carbon pencils, was used for illuminating purposes. At first a dynamo was used to run a single light, but, in the year 1878, Mr. Chas. F. Brush invented and developed the modern series arc lamp with the shunt coil, which may justly be considered the birth of the electric lighting industry of the world.

It is worthy of permanent record, as stated by Mr. Foree Bain, that "in 1879 the Maxim Electric Light Company of New York took the contract to light the exposition building in Cincinnati with arc lights. The plant consisted of ten twenty-thousand candle power lamps and ten separate dynamos for these lamps, and seven ten-thousand candle power lamps and seven corresponding dynamos, that is, a dynamo for each lamp.

"The dynamos were of the gramme ring type, with wrought-iron field magnets, stationary brush holders. The lamps were made almost entirely of brass, and were beautiful in design and finish, but they required new adjustment with each change of the current value.

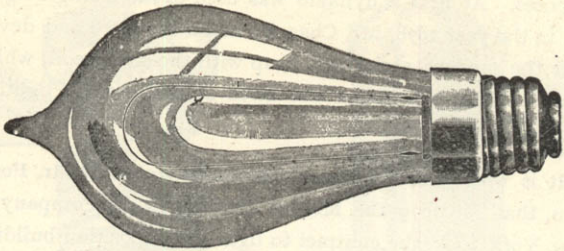
"The dynamos were marked 15 webbers.

"The circuit consisted of copper wire on one side, and gas pipes on the other side, when they were available. The copper wire was plain and uncovered, and was procured of the tinners and hardware stores.

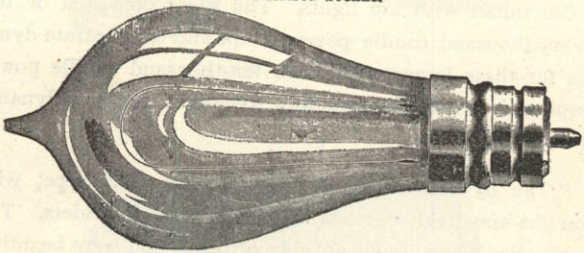
"All of the dynamos and all of the lamps were connected in parallel between the outgoing conductors and the gas

ELECTRIC LIGHTING.

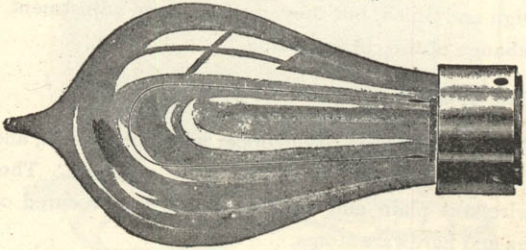
FIG. 160.



TO FIT EDISON SOCKET.



TO FIT SAWYER-MAN SOCKET.



TO FIT THOMSON-HOUSTON SOCKET.

INCANDESCENT LAMPS.

pipes. It is true the gas pipes did get quite warm, but I thought that that was an indication that the business was working well.

"In this plant I didn't have a socket, a switch, a piece of insulated wire, a fuse, an automatic cut-out, a switchboard, a ground detector, a voltmeter, an ammeter, nor an inspector's certificate. Yet the plant ran for thirty nights without a 'hitch.'"

The light of the arc lamp approaches nearest to that of sunlight af any of the artificial lights used. It is used not only for the general purposes of illumination but also extensively in photography. The arc light per candle power is much cheaper than the incandescent light, but up to the present time the arc lamp has not been successfully made in as small units.

In the field of electric lighting, there is a much greater chance for extraordinary improvements than in that of the application of power. In an "arc" light, less than ten per cent. of the energy applied is converted into light; the balance passes off in the form of heat. In incandescent lights the efficiency is still lower, being about four or five per cent.

Incandescent Lighting.—The device, with the arc light, has, more than any other, introduced electricity as an industrial agent to public approval is the incandescent lamp.

From the time of the perfection of the now familiar pear-shaped globe, with its thread-like strip of carbon, capital has

freely flowed forth from its strong vaults to the accomplishment of thousands of projects for the utilization of the electric force. It has been an illustration of the proverb that "seeing is believing."

The history of the development of the incandescent lamp is one of the most interesting to be found in the literature of inventions. Its successful accomplishment was akin to the taming a wild horse to docile service. The first strictly incandescent lamp was invented by de Molyens of Cheltenham, England, in 1841; its foundation principle was the production of a white light by the high resistance of a platinum wire to the passage of the electric current; in 1845 J. W. Starr of Cincinnati first proposed the use of carbon. Experiments soon demonstrated the great advantages of the carbon over the platinum or any other metal.

Many different forms of incandescent lamps have been made, but all are nearly of the same principle of construction, making use of the carbon filament. In 1880 Edison patented the lamp of which millions have been put into use. The manufacture of incandescent lamps has developed into enormous proportions owing to the fact that the value of the entire device is destroyed the instant the slender filament is broken—it is here as in many other manufactured articles, "the weakness of the goods is the strength of the trade."

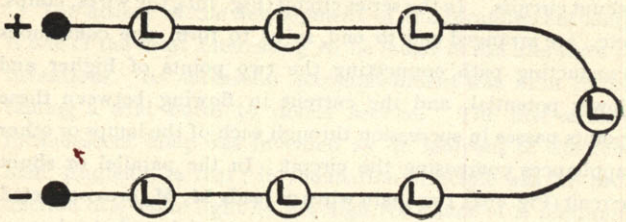
Lamp Circuits.—An electric pressure being available, it is necessary, in order to have an electric flow, to provide a continuous conducting path from the point of positive potential

to the point of negative potential. This path, whether composed simply of wires, or of lamps, motors, or other applications of electric power is called a circuit, and circuits may be divided into two kinds, viz.: series circuits, and parallel or shunt circuits. In the series circuit (Fig. 161), the wires, lamps, etc., are arranged end to end, so as to form one continuous conducting path connecting the two points of higher and lower potential, and the current in flowing between these points passes in succession through each of the lamps or other appliances composing the circuit. In the parallel or shunt circuit (Fig. 162), two main wires or leads M_1 M_2 are connected to the points of higher and lower potential, and the lamps, wires, etc., are connected across the two mains, or arranged side by side so as to form a number of independent paths or branches, and the current, in flowing from the higher to the lower potential, divides itself amongst these branches in inverse proportion to their resistance. It will be apparent that the total resistance of the parallel arrangement is less than that of any of its branches, for these, being arranged side by side, are equivalent to one having a cross section equal to the cross section of the branches. If the resistances of all the branches are equal, the total resistance of the circuit will be equal to the resistance of one branch divided by the number of branches.

The total resistance of the series circuit is evidently equal to the sum of the resistances of each of its separate parts, since these are included in one continuous path; and, for the same reason, the strength of the current flowing in a

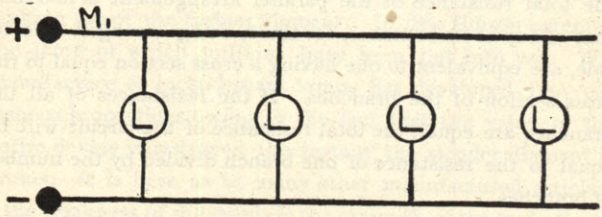
ELECTRIC LIGHTING.

FIG. 161.



SERIES CIRCUIT.

FIG. 162.



PARALLEL CIRCUIT.

series circuit is obviously everywhere the same. A circuit is said to be "closed" when it forms a continuous conducting path, and to be "open" when a discontinuity occurs in some portion such that an electric current cannot flow. When a circuit is connected or bridged across in such a manner, by some conducting material, so as to offer a resistance less than its normal working resistance, it is said to be cross-circuited or short-circuited.

Systems of Distribution.—The several methods for arranging the distribution of the electric current may be thus classified:

1. The multiple arc system.
2. The multiple series system.
3. The three-wire system.
4. The alternating transformer system.

The multiple arc system is illustrated in Fig. 163, which will readily show the method of distribution. This is also called the parallel system.

The multiple series system is represented in Fig. 164. This is a combination of the series with the parallel systems; that is, several series in parallel with each other.

The three-wire system is also illustrated in Fig. 164, where A A represent two dynamos, which are connected in such a manner that, while the total voltage of the system is 220, the lamps being connected to a third or neutral wire receive only

ELECTRIC LIGHTING.

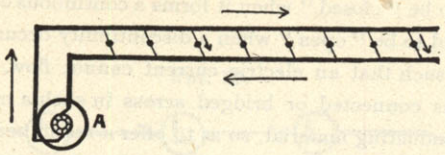
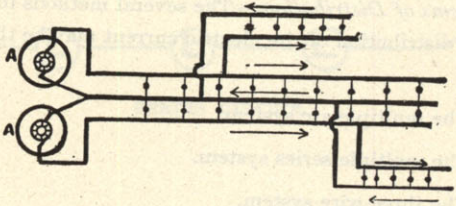
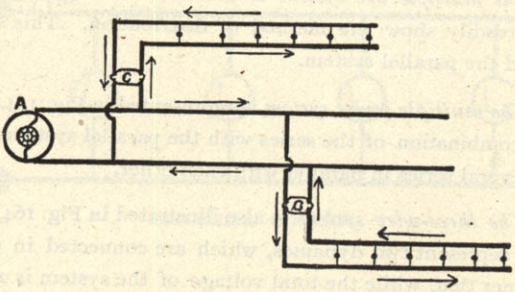
FIG. 163.

TWO WIRE INCANDESCENT SYSTEM.

FIG. 164.



THREE WIRE INCANDESCENT SYSTEM.

FIG. 165.



ALTERNATING SYSTEM.

110. By this means the voltage is doubled and the cost of copper accordingly reduced to one-fourth, or, practically, taking the central wire into consideration, to not more than three-eighths.

The alternating transformer system is shown in Fig. 165. The transformer or converter in the circuit is represented by the two letters C C.

In the alternating current system, for distribution in the open air, a high potential current is used, from 1,000 to 10,000 volts being maintained at the central station; two leads unconnected at the end lead from the station. Where current is desired, a converter is placed, whose primary is connected to the two leads, bridging the interval between them. From the secondary the house leads are taken with a low induced initial potential, in some cases of 50 volts. By the insurance rules, the converters are kept outside of buildings.

The Switchboard.—With the exception of the automatic regulation of the generator, there is nothing so important in stations operating arc lights, as the switchboard. In Fig. 159 is shown the arc plug switchboard, by the use of which any combinations either of circuits or machines are easily effected without danger of personal injury to the operator, or of disturbing or extinguishing the lights.

NOTE.—Edison's discovery of the high resistance filiment solved the problem and made it possible to use a voltage of about 110 for distributing purposes. Even this was found inadequate for large areas, and he afterwards devised the three-wire system.

ELECTRIC LIGHTING.

The Electric Lamp of the Future.—Neither of the two forms of lamp now in common use for electric lighting yields all the results that could be desired. The arc concentrates the illumination too much; the incandescent burner, while sub-dividing it, is wasteful of energy. It develops heat, and this is a net loss. The phosphorescent lamp at present requires current of too high potential and frequency of alteration to be economical. The arc lamp is yet to be touched up to more perfectly uniform action; the glow lamp is to be cheapened.

Vacuum Tube Electric Lamps.—Partial vacuum tubes known as Geisler's and Crooke's have been in use for years as a source of light in which, as is generally known, the light is produced by the passage of the electric discharge through the rarefied gas of the tube. In such light there is no combustion and only very little heat.

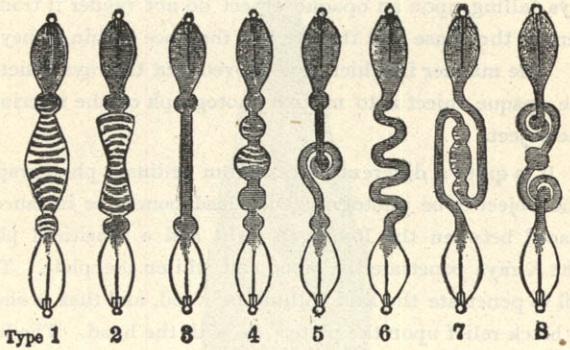
Tubes five or six feet long, three or four inches in diameter, and of any shape, may be lighted, and shine with a bluish white light, vastly brighter than any have been lighted before. The electric terminals for these tubes are not wires sealed into them, but metallic caps upon their ends. These act inductively upon and through the residual air contained in the hermetically sealed tube.

This form of lighting has been attempted before, but the results for practical purposes have not been satisfactory. The light has not been obtained in sufficient quantity, and the apparatus necessary for producing it has been expensive and

somewhat complicated, and the current employed difficult to insulate. The apparatus has now been greatly simplified and an unusual volume of light obtained from the tubes, while the current employed is under comparatively low potential.

A Geisler Tube is a glass tube containing two platinum wire terminals passing through the glass and having the air exhausted so as to leave a partial vacuum. Electric discharges or sparks pass between the two wires much more easily in a vacuum than in ordinary air. The passage of the

FIG. 166.



GEISLER TUBES.

discharge causes the air or other gas to become dimly luminous. The color of the light depends upon the kind of glass and upon the gas enclosed. Geisler tubes are sometimes made in beautiful designs. The incandescent lamp is the most common form of the Geisler tube.

ELECTRIC LIGHTING.

Crooke's Tube, or Crooke's Radiometer.—This is a device similar to the "Geisler" tube and produces the most powerful rays known to physicists.

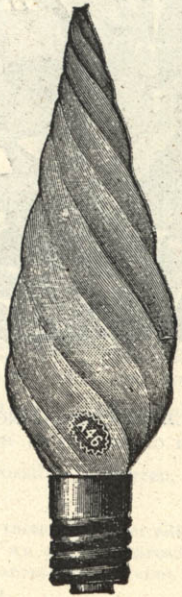
The rays, however, do not come from the visible illumination. Prof. Roentgen calls them X rays, for want of any other name. They cannot be seen. They are mysterious and unknown, except that they are proven to exist.

The remarkable property of the X rays is the power to penetrate objects opaque to the human eye, as a block of wood, the human body and thousands of other things. The rays falling upon an opaque object do not render it translucent in the sense that the eye can then see within or beyond it. The manner in which it is proved that the rays penetrate the opaque object is to make a photograph of the interior of the object.

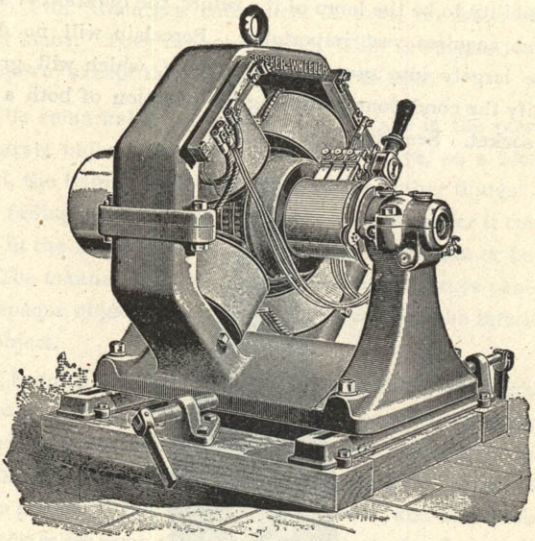
It is quite a different process from ordinary photography. The object to be photographed, a lead pencil for instance, is placed between the Roentgen light and a sensitized plate. The X rays penetrate the wood and whiten the plate. They fail to penetrate the lead within the wood, and that is shown in black relief upon the plate. So with the hand. The hand is put between the light and the plate. The X rays pass through the flesh and whiten the plate, but the rays cannot penetrate the bones, so the bones are shown in black shadow on the plate.

Standard Incandescent Lamp Sockets.—This is a question for immediate agreement among makers. It is thought the

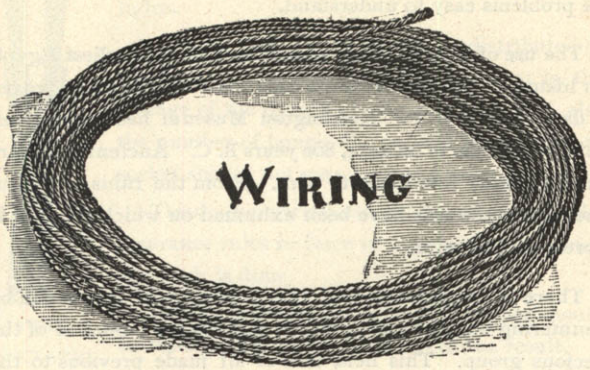
most practical and satisfactory solution is a form of base or mount so inexpensive that when the lamp is destroyed the base may be allowed to go with it as in itself a thing of no value. In view of the fact that high tension lamps are in all probability to be the lamp of the future, the question of a safe socket acquires vast importance. Porcelain will no doubt come largely into use for this purpose, which will greatly modify the conditions governing the selection of both a base and socket. See Figs. 157, 158, 160.



ORNAMENTAL LAMP.



MODEL ELECTRIC LIGHTING DYNAMO.



Whatever the source of electrical energy and whatever devices may be used to convert it into its destined purpose the transference is made by the means of wire.

Gas, water, etc., are distributed for all sorts of purposes and the laws governing them are similar to those governing electricity. Each trade has, of course, some elements which have to be considered that are neglected in others, but the main laws are common to all and do not require different interpretations except possibly in degree.

NOTE.—Size for size, a thread of spider silk, it is said, is decidedly tougher than a bar of steel. An ordinary thread will bear a weight of three grains. This is just about fifty per cent. stronger than a steel thread of the same thickness.

WIRING.

A habit of studying the distribution of electricity as is done with the distribution of steam, gas, water, etc., soon make all the problems easy to understand.

The use of wire has been traced back to the earliest Egyptian history. Specimens are in existence which can be proven to date to 1700 B. C. Kensington Museum has a specimen which was made in Minera, 800 years B. C. Ancient literature contains many references to wire. From the ruins of Herculaneum metal heads have been exhumed on which the hair is represented by wire.

There is no question that this ancient wire was made by hammering out the metal, which was always bronze or of the precious group. This held true of all made previous to the fourteenth century, during which the process of forming wire by drawing or elongating the metal by forcing it through a conical orifice, made in some substance harder than the metal treated, was invented.

The subject naturally divides itself into :

1. Electric bell wiring, including fire and burglar alarms.
2. Wiring for incandescent, or glow, lamps.
3. Wiring for arc lights.
4. Wiring for telephones and telegraphs.
5. Wiring for railway and power plants, including overhead wiring, car wiring, and station wiring.

A good wiring installation should have the following attributes :

WIRING.

FIG. 161.

TWIN INSULATED WIRE.

First, it should supply the lamps with current, and provide appropriate means of controlling the lights.

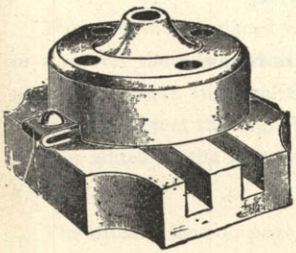
Second, the current should be distributed to the lamps at a constant pressure. That is, the voltage of the dynamo being constant, and also the number of lamps, the voltage from socket to socket should not vary beyond a certain amount.

Third, the wiring should comply with the insurance rules in force in the locality in which the work is done.

Fourth, a minimum amount of copper should be used in the accomplishment of the result.

Prof. S. P. Thompson says what is wanted is a mode of running the wires and fixing the switches and other accessories, that they shall not only be electrictight, but shall be watertight, gastight, airtight, oil-tight and rattight, and he adds that all of the above requirements, and more, are filled by a properly insulated conductor inclosed in an injury-resisting metal pipe.

FIG. 162.



PORCELAIN ROSETTE.

FIG. 163.

BINDING POST.

WIRING.

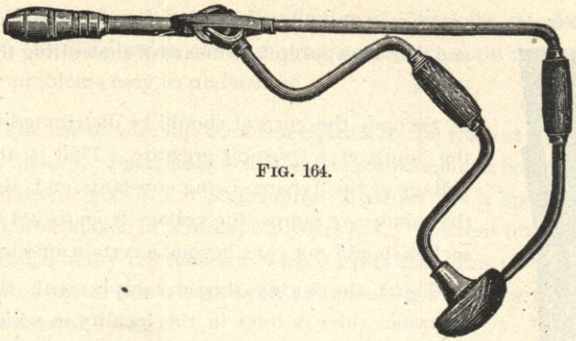


FIG. 164.

List of Tools useful for small inside wiring:

Corner Brace as shown in Fig. 164.
Several sizes of small Bits.
12″ and 24″ Twist Point Bell Hangers.
Gimlet for ⅜″ hole.
Metre Box.
Combination Handle with set of small tools.
Rat Tail File.
Small Screw Driver.
Flat Chisel.
Medium Size Hammer.
Key-hole Saw.

FUSES.

Fuse wire is a safety device designed to break the electric circuit when an excessive current passes, and it breaks the circuit because it is heated to a point at which it melts.

Other designations are "Safety Cutouts," "Safety Fuses," "Fuse Blocks" and "Safety Catches."

The main object of fuses is a protection against fire, as the fuse melts at such a low temperature that it will not set fire to inflammable material. If a short circuit was to occur on a circuit unprotected by fuse the copper would become red hot and finally melt, and if in contact with wood or other combustible material, or should the melted copper fall on anything inflammable it would be cause of a fire.

Fuses should be placed wherever the size of wire changes or wherever there is a branch of smaller size wire connected, unless the next fuse on the main or larger wire is small enough to protect the branch or small wire, but more lights may be added on the large wire, making it necessary to put in a larger.

The illustrations on page 370 show the different forms and patterns of the device.

SAFETY FUSES.

FIG. 165.

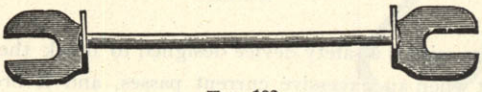


FIG. 166.

FIG. 167.

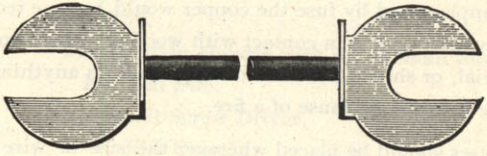


FIG. 168.

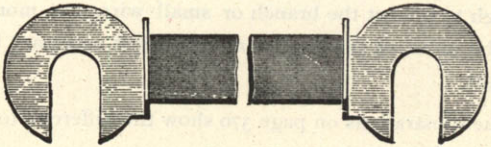


FIG. 169.

SAFETY FUSES.

"Points" relating to the Safety Fuse.

Covered fuses are more sensitive than open ones.

A fuse wire should be rated for its carrying capacity for the ordinary lenghts employed.

On important circuits fuses should be frequently renewed.

Fuses up to five amperes should be at least 1½ ins. long, ½ in. to be added for each increment of five amperes capacity.

Round fuse wires should not be employed in excess of thirty amperes capacity. For higher currents flat ribbons of four inches and upwards should be used.

Experiments have shown that for large fuses, a multiple fuse is more sensitive than a single one. A one hundred ampere fuse may be made by taking four wires of twenty-five amperes capacity.

Unless a fuse be long and quite heavy, its carrying capacity is practically the same whether it be placed vertically or horizontally.

Experience seems to show that the best alloy for a fuse is one of lead and tin, the lead being considerably in excess. If too much lead is used, the fuses deteriorate rapidly and coat with the white film.

A fuse block may be overloaded, not because the metal of the terminals is not of sufficient cross-section to carry the current, but because of insufficient area of, or loose contact of, fuse, or wires, and this heating is very frequently the cause of fuses melting.

SAFETY FUSES.

Wires and fuses should be screwed up tight, as it is frequently the case the area of contact of wires or fuse is not sufficient to prevent heating when there is a full load on the wires.

The area of contact should be several times the cross-section of the wires connected and for that reason, in the case of large size wires, the ends should be flattened if connected under the head of a binding screw.

A leading question now is the automatic circuit breaker *versus* the fuse wire. Both these devices are excellent in themselves, but each requires judgement in selection and use. The automatic circuit breaker is to be preferred for switch board use and motor service. A circuit breaker placed in plain sight on the front of the board is to be preferred in all cases.

For lighting circuits, it is doubtful if any simpler and better device than the fuse wire can be used. In spite of all that has been said against it, when properly used and taken care of, it leaves little or nothing to be desired; yet there is nothing about the plant that is more dangerous when ignorantly or carelessly used.

THE TELEGRAPH.

Telegraph companies on their long lines use batteries of from twenty to a hundred cells each.

IMPORTANT.

The National Code is said to be the wiremen's Bible; it says "thou shalt not use this, and thou shalt not do that," and it also contains for him who will study it, the principles which enable him to decide what he ought to do.

The code is not intended to be a cast-iron set of regulations or a complete specification of how to do construction, but it is designed to serve as the common law of electrical construction, to indicate what things must always be done, what must never be done, and to set forth the principles which should be observed in order to secure safety. It is the spirit of the code, even more than the letter, that should be studied by the architect and the engineer.

It is impossible to conceive a set of regulations which would describe all the necessary requirements of good work, but an observance of the principles underlying these rules will enable us to determine what material and construction is suitable and what is best for each particular case.

WIRING RULES AND REQUIREMENTS.

National Board Fire Underwriters.

RULES AND REQUIREMENTS

Of the National Board of Fire Underwriters for the Installation of Wiring and Apparatus for Electric Light and Power as Recommended by the Underwriters' and National Electric Association.

The use of wire ways for rendering concealed wiring permanently accessible is most heartily endorsed and recommended; and this method of accessible concealed construction is advised for general use.

Architects are urged, when drawing plans and specifications, to make provisions for the channeling and pocketing of buildings for electric light or power wires, and in specifications for electric gas lighting to require a two-wire circuit, whether the building is to be wired for electric lighting or not, so that no part of the gas fixtures or gas piping be allowed to be used for the gas lighting circuit.

Class A. Central Stations for Light or Power.

These Rules also apply to Dynamo Rooms in Isolated Plants, connected with or detached from buildings used for other purposes; also to all varieties of apparatus therein of both high and low potential.

WIRING RULES AND REQUIREMENTS.

1. GENERATORS:

a. Must be located in a dry place.

b. Must be insulated on floors or base frames, which must be kept filled, to prevent absorption of moisture, and also kept clean and dry.

c. Must never be placed in a room where any hazardous process is carried on, nor in places where they would be exposed to inflammable gases, or flyings of combustible material.

d. Must each be provided with a waterproof covering.

2. CARE AND ATTENDANCE:

A competent man must be kept on duty in the room where generators are operating.

Oily waste must be kept in *approved* metal cans and removed daily.

3. CONDUCTORS:

From generators, switchboards, rheostats or other instruments, and thence to outside lines, conductors—

a. Must be in plain sight and readily accessible.

b. Must be wholly on non-combustible insulators, such as glass or porcelain.

c. Must be separated from contact with floors, partitions or walls through which they may pass, by non-combustible insulating tubes, such as glass or porcelain.

d. Must be kept rigidly so far apart that they cannot come in contact.

e. Must be covered with non-inflammable insulating material sufficient to prevent accidental contact, except that "bus bars" may be made of bare metal.

NATIONAL BOARD FIRE UNDERWRITERS.

f. Must have ample carrying capacity, to prevent heating. (See Capacity of Wires Table.)

4. SWITCHBOARDS:

a. Must be so placed as to reduce to a minimum the danger of communicating fire to adjacent combustible material.

b. Must be accessible from all sides when the connections are on the back; or may be placed against a brick or stone wall when the wiring is entirely on the face.

c. Must be kept free from moisture.

d. Must be made of non-combustible material, or of hard wood in skeleton form, filled to prevent absorption of moisture.

e. Bus bars must be equipped in accordance with Rule 3 for placing conductors.

5. RESISTANCE BOXES AND EQUALIZERS:

a. Must be equipped with metal, or other non-combustible frames. (See Definitions.)

b. Must be placed on the switchboard, or, if not thereon, at a distance of a foot from combustible material, or separated therefrom by a non-inflammable, non-absorptive, insulating material.

6. LIGHTNING ARRESTERS:

a. Must be attached to each side of every overhead circuit connected with the station.

b. Must be mounted on non-combustible bases in plain sight on the switchboard, or in any equally accessible place, away from combustible material.

c. Must be connected with at least two " earths " by separate wires, not smaller than No. 6 B. & S., which must not be connected to any pipe within the building, and must be run as nearly as possible in a straight line from the arresters to the earth connection.

d. Must be so constructed as not to maintain an arc after the discharge has passed.

7. TESTING:

a. All series and alternating circuits must be tested every two hours while in operation, to discover any leakage to earth, abnormal in view of the potential and method of operation.

b. All multiple arc low potential systems (300 volts or less) must be provided with an indicating or detecting device, readily attachable, to afford easy means of testing where the station operates continuously.

c. Data obtained from all tests must be preserved for examination by insurance inspectors.

These rules on testing to be applied at such places as may be designated by the association having jurisdiction.

8. MOTORS:

a. Must be wired under the same precautions as with a current of the same volume and potential for lighting. The motor and resistance box must be protected by a double pole cut-out and controlled by a double-pole switch, except in cases where one-quarter horse-power or less is used on low tension circuit, a single pole switch will be accepted.

NATIONAL BOARD FIRE UNDERWRITERS.

b. Must be thoroughly insulated, mounted on filled dry wood, be raised at least eight inches above the surrounding floor, be provided with pans to prevent oil from soaking into the floor, and must be kept clean.

c. Must be covered with a waterproof cover when not in use, and, if deemed necessary by the Inspector, be inclosed in an *approved* case. (See Definitions.)

9. RESISTANCE BOXES:

a. Must be equipped with metal or other non-combustible frames. (See Definitions.)

b. Must be placed on the switchboard, or at a distance of a foot from combustible material, or separated therefrom by a non-inflammable, non-absorptive, insulating material.

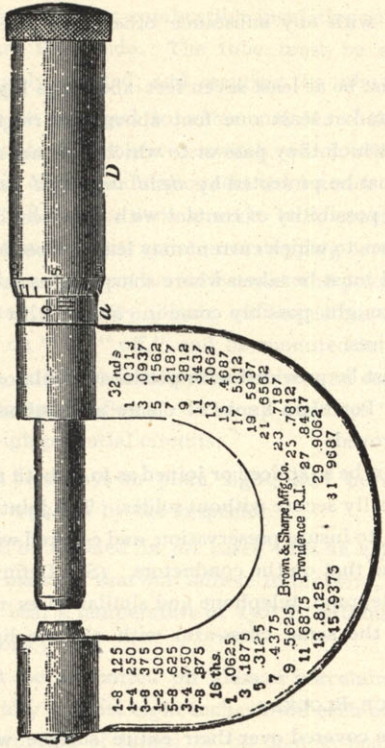
Class B. High Potential Systems, over 300 Volts.

Any circuit attached to any machine, or combination of machines, which develop over 300 volts difference of potential between any two wires, shall be considered as a high potential circuit and coming under that class, unless an approved transforming device is used, which cuts the difference of potential down to less than 300 volts.

10. OUTSIDE CONDUCTORS—ALL OUTSIDE, OVERHEAD CONDUCTORS (INCLUDING SERVICES):

a. Must be covered with some *approved* insulating material, not easily abraded, firmly secured to properly insulated and substantially built supports, all tie wires having an insulation equal to that of the conductors they confine. (See Definitions.)

FIG. 170.



MICROMETER WIRE GUAGE.

b. Must be so placed that moisture cannot form a cross connection between them, not less than a foot apart, and not in contact with any substance other than their insulating supports.

c. Must be at least seven feet above the highest point of flat roofs, and at least one foot above the ridge of pitched roofs over which they pass or to which they are attached.

d. Must be protected by *dead insulated guard irons* or *wires* from possibility of contact with other conducting wires or substances to which current may leak. Special precautions of this kind must be taken where sharp angles occur, or where any wires might possibly come in contact with electric light or power wires.

e. Must be provided with petticoat insulators of glass or porcelain. Porcelain knobs or cleats and rubber hooks will not be approved.

f. Must be so spliced or joined as to be both mechanically and electrically secure without solder. The joints must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors. (See Definitions.)

g. Telegraph, telephone and similar wires must not be placed on the same cross-arm with electric light or power wires.

11. SERVICE BLOCKS:

Must be covered over their entire surface with at least two coats of waterproof paint.

12. ALL INTERIOR CONDUCTORS:

a. Must be covered where they enter buildings from outside terminal insulators to and through the walls, with

NATIONAL BOARD FIRE UNDERWRITERS.

extra waterproof insulation, and must have drip loops outside. The hole through which the conductor passes must be bushed with waterproof and non-combustible insulating tube, slanting upward toward the inside. The tube must be sealed with tape, thoroughly painted, and securing the tube to the wire.

b. Must be arranged to enter and leave the building through a double contact service switch, which will effectually close the main circuit aud disconnect the interior wires when it is turned "off." The switch must be so constructed that it shall be automatic in its action, not stopping between points when started, and prevent an arc between the points under all circumstances; it must indicate on inspection whether the current be "on" or "off," and be mounted in a non-combustible case, and kept free from moisture, and easy of access to police or firemen. So-called "snap switches" shall not be used on high potential circuits.

c. Must be always in plain sight, and never encased, except when *required* by the Inspector.

d. Must be covered in all cases with an *approved* non-combustible material that will adhere to the wire, not fray by friction, and bear a temperature of 150° F. without softening. (See Definitions.)

e. Must be supported on glass or porcelain insulators, and kept rigidly at least eight inches from each other, except within the structure of lamps or on hanger-boards, cut-out boxes, or the like, where less distance is necessary.

f. Must be separated from conctact with walls, floors, timbers or partitions through which they may pass by non-combustible insulating tube.

g. Must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors.

13. ARC LAMPS—IN EVERY CASE:

a. Must be carefully isolated from inflammable material.

b. Must be provided at all times with a glass globe surrounding the arc, securely fastened upon a closed base. No broken or cracked globes to be used.

c. Must be provided with an *approved* hand-switch, also an automatic switch, that will shunt the current around the carbons should they fail to feed properly. (See Definitions.)

d. Must be provided with reliable stops to prevent carbons from falling out in case the clamps become loose.

e. Must be carefully insulated from the circuit in all their exposed parts.

f. Must be provided with a wire netting around the globe, and an *approved* spark arrester above to prevent escape of sparks, melted copper, or carbon, where readily inflammable material is in the vicinity of the lamps. It is recommended that plain carbons, not copper-plated, be used for lamps in such places. (See Definitions.)

g. Hanger-boards must be so constructed that all wires and current-carrying devices thereon shall be exposed to view and thoroughly insulated by being mounted on a waterproof non-combustible substance. All switches attached to the same must be so constructed that they shall be automatic in their action, not stopping between points when started, and preventing an arc between points under all circumstances.

NATIONAL BOARD FIRE UNDERWRITERS.

h. Where hanger boards are not used, lamps to be hung from insulated supports other than their conductors.

14. INCANDESCENT LAMPS IN SERIES CIRCUITS HAVING A MAXIMUM POTENTIAL OF 300 VOLTS OR OVER:

a. Must be governed by the same rules as for arc lights, and each series lamp provided with an *approved* hand spring switch and automatic cut-out.

b. Must have each lamp suspended from a hanger-board by means of a rigid tube.

c. No electro-magnetic device for switches and no system of multiple series or series multiple lighting will be approved.

d. Under no circumstances can series lamps be attached to gas fixtures.

Class C. Low Potential Systems, 300 Volts or less.

15. OUTSIDE OVERHEAD CONDUCTORS:

a. Must be erected in accordance with the rules for high potential conductors.

b. Must be separated not less than 12 inches, and be provided with an *approved* fusible cut-out, that will cut off the entire current as near as possible to the entrance to the building and inside the walls (See Definitions.)

16. UNDERGROUND CONDUCTORS:

a. Must be protected against moisture and mechanical injury, and be removed at least two feet from combustible material when brought into a building, but not connected with the interior conductors.

b. Must have a switch and a cut-out for each wire between the underground conducters and the interior wiring when the two parts of the wiring are connected.

These switches and fuses must be placed as near as possible to the end of the underground conduit, and connected therewith by specially insulated conductors, kept apart not less than two and one-half inches. (See Definitions.)

c. Must not be so arranged as to shunt the current through a building around any catch-box.

17. INSIDE WIRING—GENERAL RULES :

At the entrance of every building there shall be an *approved* switch placed in the service conductors by which the current may be entirely cut off. (See Definitions.)

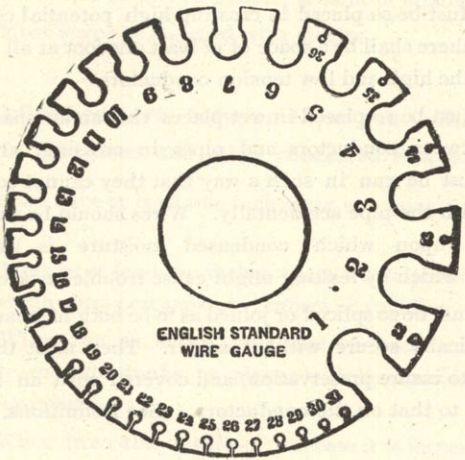
18. CONDUCTORS :

a. Must have an *approved* insulating covering, and must not be of sizes smaller than No. 14 B. & S., No. 16 B. W. G., or No. 4 E. S. G., except that in conduit installed under Rule 22, No. 16 B. & S., No. 18 B. W. G., or No. 4 E. S. G. may be used. (See Definitions.)

b. Must be protected when passing through floors ; or through walls, partitions, timbers, etc., in places liable to be exposed to dampness by waterproof, non-combustible, insulating tubes, such as glass or porcelain.

Must be protected when passing through walls, partitions, timbers, etc., in places not liable to be exposed to dampness by *approved* insulating bushings specially made for the purpose. (See Definitions.)

FIG. 171.



BIRMINGHAM WIRE GAUGE (B. W. G.)

NATIONAL BOARD FIRE UNDERWRITERS.

c. Must be kept free from contact with gas, water or other metallic piping, or any other conductors or conducting material which they may cross (except high potential conductors) by some continuous and firmly fixed non-conductor creating a separation of at least one inch. Deviations from this rule may sometimes be allowed by special permission.

d. Must be so placed in crossing high potential conductors that there shall be a space of at least one foot at all points between the high and low tension conductors.

e. Must be so placed in wet places that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally. Wires should be run *over* all pipes upon which condensed moisture is likely to gather, or which by leaking might cause trouble on a circuit.

f. Must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors. (See Definitions.)

Special Rules.

19. WIRING NOT ENCASED IN MOULDING OR APPROVED CONDUIT:

a. Must be supported wholly on non-combustible insulators, constructed so as to prevent the insulating coverings of the wire from coming in contact with other substances than the insulating supports.

WIRING RULES AND REQUIREMENTS.

b. Must be so arranged that wires of opposite polarity, with a difference of potential of 150 volts or less, will be kept apart at least two and one-half inches.

c. Must have the above distance increased proportionately where a higher voltage is used.

d. Must not be laid in plaster, cement or similar finish.

e. Must never be fastened with staples.

In Unfinished Lofts between Floor and Ceilings, in Partitions and other concealed Places.

f. Must have at least one inch clear air space surrounding them.

g. Must be at least ten inches apart when possible, and should be run singly on separate timbers or studding.

h. Wires run as above immediately under roofs, in proximity to water-tanks or pipes, will be considered as exposed to moisture.

i. When from the nature of the case it is impossible to place concealed wire on non-combustible insulating supports of glass or porcelain, the wires may be fished on the loop system, if incased throughout in *approved* continuous flexible tubing or conduit.

j. Wires must not be fished for any great distance, and only in places where the Inspector can satisfy himself that the above rules have been complied with.

k. Twin wires must never be employed in this class of concealed work.

NATIONAL BOARD FIRE UNDERWRITERS.

20. MOULDINGS :

a. Must never be used in concealed work or in damp places.

b. Must have at least two coats of waterproof paint or be impregnated with a moisture repellant.

c. Must be made of two pieces, a backing and capping, so constructed as to thoroughly incase the wire and maintain a distance of one-half inch between conductors of opposite polarity and afford suitable protection from abrasion.

21. SPECIAL WIRING :

In breweries, packing-houses, stables, dye houses, paper and pulp mills, or other buildings specially liable to moisture or acid, or other fumes liable to injure the wires or insulation, except where used for pendants, conductors—

a. Must be separated at least six inches.

b. Must be provided with an *approved* water-proof covering. (See Definitions.)

c. Must be carefully put up.

d. Must be supported by glass or porcelain insulators. No switches or fusible cut-outs will be allowed where exposed to inflammable gases or dust, or to flyings of combustible material.

e. Must be protected when passing through floors, walls, partitions, timbers, etc., by water-proof, non-combustible, insulating tubes, such as glass or porcelain.

22. INTERIOR CONDUITS* : (See Definitions.)

a. Must be continuous from one junction box to another, or to fixtures, and must be of material that will resist the

* The object of a tube or conduit is to facilitate the insertion or extraction of the conductors to protect them from mechanical injury, and as far as possible, from moisture. Tubes or conduits are to be considered merely as raceways, and are not to be relied on for insulation between wire and wire, or between the wire and the ground.

fusion of the wire or wires they contain without igniting the conduit.

b. Must not be of such material or construction that the insulation of the conductor will ultimately be injured or destroyed by the elements of the composition.

c. Must be first installed as a complete conduit system, without conductors, strings or anything for the purpose of drawing in the conductors, and the conductors then to be pushed or fished in. The conductors must not be placed in position until all mechanical work on the building has been, as far as possible, completed.

d. Must not be so placed as to be subject to mechanical injury by saws, chisels or nails.

e. Must not be supplied with a twin conductor, or two separate conductors, in a single tube. (See Rule 22.)

f. *Must have all ends closed* with good adhesive material, either at junction boxes or elsewhere, whether such ends are concealed or exposed. Joints must be made air-tight and moisture proof.

g. Conduits must extend at least one inch beyond the finished surface of walls or ceilings until the mortar or other similar material be entirely dry, when the projection may be reduced to half an inch.

23. DOUBLE POLE SAFETY CUT-OUTS:

a. Must be in plain sight or enclosed in an *approved* box, readily accessible. (See Definitions.)

b. Must be placed at every point where a change is made in the size of the wire (unless the cut-out in the larger wire will protect the smaller).

NATIONAL BOARD FIRE UNDERWRITERS.

c. Must be supported on bases of non-combustible, insulating, moisture-proof material.

d. Must be supplied with a plug (or other device for enclosing the fusible strip or wire) made of non-combustible and moisture-proof material, and so constructed that an arc cannot be maintained across its terminals by the fusing of the metal.

e. Must be so placed that on any combination fixture no group of lamps requiring a current of six amperes or more shall be ultimately dependent upon one cut-out. Special permission may be given *in writing* by the Inspector for departure from this rule in case of large chandeliers.

f. All cut-out blocks must be stamped with their *maximum* safe-carrying capacity in amperes.

24. SAFETY FUSES:

a. Must all be stamped or otherwise marked with the number of amperes they will carry indefinitely without melting.

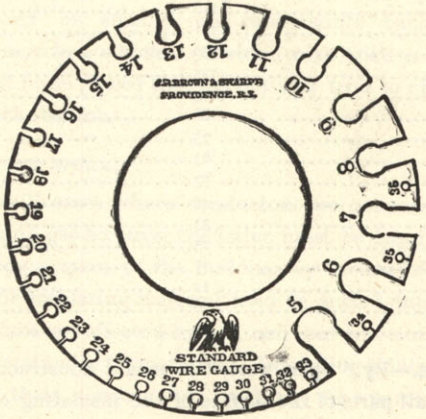
b. Must have fusible wires or strips (where the plug or equivalent device is not used), with contact surfaces or tips of harder metal, soldered or otherwise, having perfect electrical connections with the fusible part of the strip.

c. Must all be so proportioned to the conductors they are intended to protect that they will melt before the maximum safe-carrying capacity of the wire is exceeded.

25. TABLE OF CAPACITY OF WIRES:

It must be clearly understood that the size of the fuse depends upon the size of the smallest conductor it protects,

FIG. 172.



BROWN & SHARPE WIRE GUAGE (B. & S. W. G.)

WIRING RULES AND REQUIREMENTS.

and not upon the amount of current to be used on the circuit. Below is a table showing the safe-carrying capacity of conductors of different sizes in Brown & Sharpe gauge, which must be followed in the placing of interior conductors:

	TABLE A. Concealed Work.	TABLE B. Open Work.
B. & S. G.	Amperes.	Amperes.
0000	218	312
000	181	262
00	150	220
0	125	185
1	105	156
2	88	131
3	75	110
4	63	92
5	53	77
6	45	65
8	33	46
10	25	32
12	17	23
14	12	16
16	6	8
18	3	5

NOTE.—By "open work" is meant construction which admits of all parts of the surface of the insulating covering of the wire being surrounded by *free* air. The carrying capacity of 16 and 18 wire is given, but no wire smaller than 14 is to be used except as allowed under Rules 18 (*a*) and 27 (*d*).

26. SWITCHES:

a. Must be mounted on moisture-proof and non-combustible bases, such as slate or porcelain.

b. Must be double pole when the circuits which they control supply more than six 16 candle-power lamps, or their equivalent.

NATIONAL BOARD FIRE UNDERWRITERS.

c. Must have a firm and secure contact; must make and break readily, and not stop when motion has once been imparted by the handle.

d. Must have carrying capacity sufficient to prevent heating.

e. Must be placed in dry, accessible places, and be grouped as far as possible, being mounted—when practicable—upon slate or equally non-combustible back boards. Jackknife switches, whether provided with friction or spring stops, must be so placed that gravity will tend to open rather than close the switch.

27. FIXTURE WORK.

a. In all cases where conductors are concealed within or attached to gas fixtures, the latter must be insulated from the gas pipe system of the building by means of *approved* joints. The insulating material used in such joints must be of a substance not affected by gas, and that will not shrink or crack by varation in temperature. Insulating joints, with soft rubber in their construction, will not be approved. (See Definitions.)

b. Supply conductors and especially the splices to fixture wires, must be kept clear of the grounded part of gas pipes, and where shells are used the latter must be constructed in a manner affording sufficient area to allow this requirement.

c. When fixtures are wired outside, the conductors must be so secured as not to be cut or abraded by the pressure of the fastenings or motion of the fixture.

d. All conductors for fixture work must have a water proof insulation that is durable and not easily abraded, and

must not in any case be smaller than No. 18 B. & S., No. 20 B. W. G., No. 2 E. S. G.

e. All burrs or fins must be removed before the conductors are drawn into a fixture.

f. The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture

g. No combination fixture in which the conductors are concealed in a space less than one-fourth inch between the inside pipe and the outside casing will be approved.

h. Each fixture must be tested for "contacts" between conductors and fixtures, for "short circuits," and for ground connections before the fixture is connected to its supply conductors.

i. Ceiling blocks of fixtures should be made of insulating material; if not, the wires in passing through the plate must be surrounded with hard rubber tubing.

28. ARC LIGHTS ON LOW POTENTIAL CIRCUITS:

a. Must be supplied by branch conductors not smaller than No. 12 B. & S. gauge.

b. Must be connected with main conductors only through double pole cut-outs.

c. Must only be furnished with such resistances or regulators as are enclosed in non-combustible material, such resistances being treated as stoves.

Incandescent lamps must not be used for resistance devices.

d. Must be supplied with globes and protected as in the case of arc lights on high potential circuits.

NATIONAL BOARD FIRE UNDERWRITERS.

29. ELECTRIC GAS LIGHTING:

Where electric gas lighting is to be used on the same fixture with the electric light—

a. No part of the gas piping or fixture shall be in electrical connection with the gas lighting circuit.

b. The wires used with the fixtures must have a non-inflammable insulation, or, where concealed between the pipe and the shell of the fixture, the insulation must be such as required for fixture wiring for the electric light.

c. The whole installation must test free from "grounds."

d. The two installations must test perfectly free from connection with each other.

30. SOCKETS:

a. No portion of the lamp socket exposed to contact with outside objects must be allowed to come into electrical contact with either of the conductors.

b. In rooms where inflammable gases may exist, or where the atmosphere is damp, the incandescent lamp and socket should be enclosed in a vapor-tight globe.

31. FLEXIBLE CORD:

a. Must be made of conductors, each surrounded with a moisture-proof and non-inflammable layer, and further insulated from each other by a mechanical separator of carbonized material. Each of these conductors must be composed of several strands.

b. Must not sustain more than one light not exceeding 50 candle-power.

c. Must not be used except for pendants, wiring of fixtures and portable lamps or motors.

d. Must not be used in show windows.

e. Must be protected by insulating bushings where the cord enters the socket. The ends of the cord must be taped to prevent fraying of the covering.

f. Must be so suspended that the entire weight of the socket and lamp will be borne by knots under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws.

g. Must be equipped with keyless sockets as far as practicable, and be controlled by wall switches.

32. DECORATIVE SERIES LAMPS:

Incandescent lamps run in series circuits shall not be used for decorative purposes inside of buildings.

Class D. Alternating Systems.—Converters or Transformers.

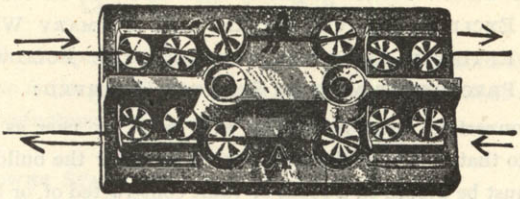
33. CONVERTERS:

a. Must not be placed inside of any building, except the Central Station, unless by special permission of the Underwriters having jurisdiction.

b. Must not be placed in any but metallic or other noncombustible cases.

c. Must not be attached to the outside walls of buildings, unless separated therefrom by substantial insulating supports.

FIG. 173.



LINE CUTOUT.

FIG. 174.

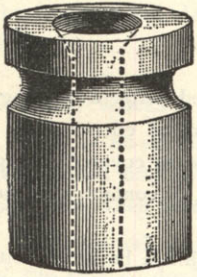
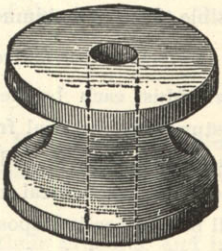
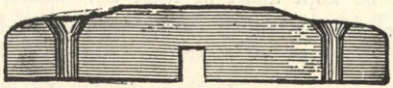


FIG. 175.



PORCELAIN INSULATORS.

FIG. 176.



WOOD CLEAT.

NATIONAL BOARD FIRE UNDERWRITERS.

34. In those Cases where it may not be Possible to Exclude the Converters and Primary Wires Entirely from the Building, the Following Precautions must be Strictly Observed:

Converters must be located at a point as near as possible to that at which the primary wires enter the building, and must be placed in a room or vault constructed of, or lined with, fire-resisting material, and used only for the purpose. They must be effectually insulated from the ground, and the room in which they are placed be practically air-tight, except that it shall be thoroughly ventilated to the out-door air, if possible through a chimney or flue.

35. Primary Conductors:

a. Must each be heavily insulated with a coating of moisture-poof material from the point of entrance to the transformer, and, in addition, must be so covered and protected that mechanical injury to them, or contact with them, shall be practically impossible.

b. Must each be furnished, if within a building, with a switch and a fusible cut-out where the wires enter the building, or where they leave the main line, on the pole or in the conduit. These switches should be enclosed in secure and fire-proof boxes preferably outside the building.

c. Must be kept apart at least ten inches, and at the same distance from all other conducting bodies when inside a building.

36. Secondary Conductors:

Must be installed according to the rules for "Low Potential Systems."

WIRING RULES AND REQUIREMENTS.

Class E. Electric Railways.

37. All rules pertaining to arc light wires and stations shall apply (so far as possible) to street railway power stations and their conductors in connection with them.

38. POWER STATIONS:

Must be equipped in each circuit as it leaves the station with an *approved* automatic "breaker," or other device that will immediately cut off the current in case the trolley wires become grounded. This device must be mounted on a fire-proof base, and in full view and reach of the attendant. (See Definitions.)

39. TROLLEY WIRES:

a. Must be no smaller than No. 0, B. & S. copper or No. 4, B. & S. silicon bronze, and must readily stand the strain put upon them when in use.

b. Must be well insulated from their supports, and in case of the side or double pole construction, the supports shall also be insulated from the poles immediately outside of the trolley wire.

c. Must be capable of being disconnected at the power house, or of being divided into sections, so that in case of fire on the railway route the current may be shut off from the particular section and not interfere with the work of the firemen. This rule also applies to *feeders.*

d. Must be safely protected against contact with all other conductors.

NATIONAL BOARD FIRE UNDERWRITERS.

40. CAR WIRING:

Must be always run out of reach of the passengers, and must be insulated with a water-proof insulation.

41. LIGHTING AND POWER FROM RAILWAY WIRES:

Must not be permitted, under any pretense, in the same circuit with trolley wires with a ground return, nor shall the same dynamo be used for both purposes, except in street railway cars, electric car houses, and their power station.

42. CAR HOUSES:

Must have special cut-outs located at a proper distance outside, so that all circuits within any car house can be cut out at one point.

43. GROUND RETURN WIRES:

Where ground return is used it must be so arranged that no difference of potential will exist greater than five volts to fifty feet, or fifty volts to the mile between any two points in the earth or pipes therein.

Class F.

44. STORAGE OR PRIMARY BATTERIES:

a. When current for light and power is taken from primary or secondary batteries, the same general regulations must be observed as applied to similar apparatus fed from dynamo generators developing the same difference of potential.

WIRING RULES AND REQUIREMENTS.

. All secondary batteries must be mounted on *approved* insulators.

c. Special attention is directed to the rules for rooms where acid fumes exit.

d. The use of any metal liable to corrosion must be avoided in connections of secondary batteries.

Miscellaneous.

45. *a.* The wiring in any building must test free from grounds; *i. e.*, each main supply line and every branch circuit shall have an insulation resistance of at least 25,000 ohms, and should have an insulation resistance between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following:

Up to	10	amperes,	4,000,000
"	25	"	1,000,000
"	50	"	800,000
"	100	"	300,000
"	200	"	160,000
"	400	"	80,000
"	800	"	22,000
"	1,600	"	11,000

All cut-outs and safety devices in place in the above.

Where lamp sockets, receptacles, and electroliers, etc., are connected, one-half of the above will be required.

b. Ground wires for lightning arresters of all classes, and ground detectors, must not be attached to gas pipes within the building.

NATIONAL BOARD FIRE UNDERWRITERS.

c. Where telephone, telegraph or other wires connected with outside circuits are bunched together within any building, or where inside wires are laid in conduit or duct with electric light or power wires, the covering of such wires must be fire resisting, or else the wires must be inclosed in an air-tight tube or duct.

d. All conductors connecting with telephone, district messenger, burglar-alarm, watch-clock, electric-time, and other similar instruments, must be provided near the point of entrance to the building with some protective device which will operate to shunt the instruments in case of a dangerous rise of potential, and will open the circuit and arrest an abnormal current flow. Any conductor normally forming an innocuous circuit may become a source of fire hazard if crossed with another conductor, through which it may become charged with a relatively high pressure. (See Definitions.)

e. The following formula for soldering fluid is suggested:

Saturated solution of zinc	5 parts
Alcohol	4 parts
Glycerine	1 part

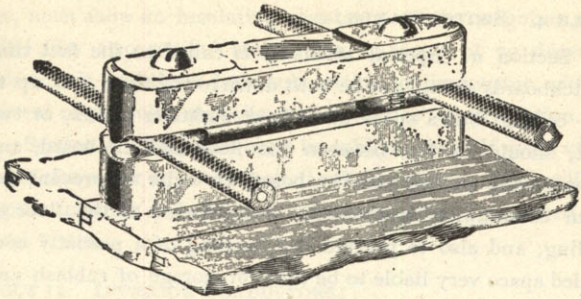
DEFINITIONS

of the word APPROVED as used in these rules, and notice of the approval of certain wires and materials, and the interpretation of certain rules.

RULE 2. CARE AND ATTENDANCE:

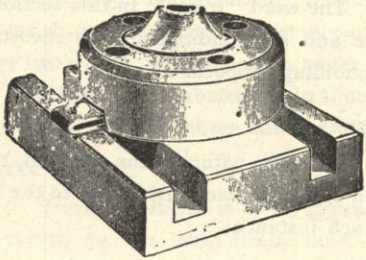
Approved waste cans shall be made of metal, with legs raising can three inches from the floor, and with self-closing covers.

FIG. 177.



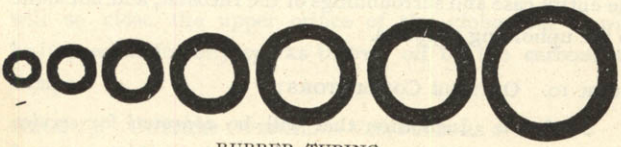
PORCELAIN CLEAT.

FIG. 178.



PORCELAIN ROSETTE.

FIG. 179.



RUBBER TUBING.

WIRING RULES AND REQUIREMENTS.

RULE 4. SWITCHBOARDS:

Section *a*. Special attention is called to the fact that switchboards should not be built down to the floor, nor up to the ceiling, but a space of at least eighteen inches, or two feet, should be left between the floor and the board, and between the ceiling and the board, in order to prevent fire from communicating from the switchboard to the floor or ceiling, and also to prevent the forming of a partially concealed space very liable to be used for storage of rubbish and oily waste.

RULE 5. RESISTANCE BOXES:

Section *a*. The word "frame" in this section relates to the entire case and surroundings of the rheostat, and not alone to the upholding supports.

RULE 8. MOTORS:

Section *e*. From the nature of the question, the decision as to what is an *approved* case must be left to the Inspector to determine in each instance.

RULE 9. RESISTANCE BOXES:

Section *a*. The word "frame" in this section relates to the entire case and surroundings of the rheostat, and not alone to the upholding supports.

RULE 10. OUTSIDE CONDUCTORS:

Section *a*. Iusulation that will be *approved* for service wires must be solid, at least $\frac{3}{64}$ of an inch in thickness, and covered with a substantial braid. It must not readily carry

NATIONAL BOARD FIRE UNDERWRITERS.

fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Fahrenheit, and three days' submersion in lime water, with a current of 550 volts, and after three minutes' electrification.

Section *f*. All joints must be soldered, even if made with the McIntyre or any other patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these Rules.

RULE 12. INTERIOR CONDUCTORS:

Section *d*. Insulation that will be *approved* for interior conductors must be solid, at least $\frac{3}{64}$ of an inch in thickness, and covered with a substantial braid. It must not readily carry fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Fahrenheit, and three days' submersion in lime water, with a current of 550 volts, and after three minutes' electrification.

RULE 13. ARC LAMPS:

Section *c*. The hand switch is to be *approved*, if placed any where except on the lamp itself, must comply with requirements for switches on hanger-boards as laid down in Section *g* of Rule 13.

Section *f*. An *approved* spark arrester is one which will so close the upper orifice of the globe that it will be impossible for any sparks thrown off by the carbons to escape.

RULE 15. OUTSIDE OVERHEAD CONDUCTORS:

Section *b*. An *approved* fusible cut-out must comply with the sections of Rules 23 and 24 describing fuses and cut-outs.

WIRING RULES AND REQUIREMENTS.

The cut-out required by this section must be placed so as to protect the switch required by Rule 17.

RULE 16. UNDERGROUND CONDUCTORS:

Section *b*. The cut-out required by this section must be placed so as to protect the switch.

RULE 17:

The switch required by this rule to be *approved* must be double pole, must plainly indicate whether the current is "on" or "off," and must comply with Sections *a*, *c*, *d* and *e* of Rule 26 relating to switches.

RULE 18. CONDUCTORS:

Section *a*. In so-called "concealed" wiring, moulding and conduit work, *and* in places liable to be exposed to dampness, the insulating covering of the wire, to be *approved*, must be solid, at least $\frac{8}{64}$ of an inch in thickness, and covered with a substantial braid. It must not readily carry fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Fahrenheit, and three days' submersion in lime water, with a current of 550 volts, and after three minutes' electrification.

For work which is *entirely* exposed to view throughout the whole interior circuits, and not liable to be exposed to dampness, a wire with an insulating covering that will not support combustion, will resist abrasion, is at least $\frac{1}{16}$ of an inch in thickness, and thoroughly impregnated with a moisture repellant, will be *approved*.

NATIONAL BOARD FIRE UNDERWRITERS.

Section *b*. Second paragraph. Except for floors, *and* for places liable to be exposed to dampness, glass, porcelain, *metal sheathed* Interior Conduit and Vulca Tube, when made especially for bushings, will be *approved*. [The two last named will not be approved if cut from the usual lengths of tube made for conduit work, nor when made without a head or flange on one end.]

Section *f*. All joints must be soldered, even if made with the McIntyre or any other patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these Rules.

RULE 21. SPECIAL WIRING :

Section *b*. The insulating covering of the wire to be *approved* under this section must be solid, at least $\frac{3}{64}$ of an inch in thickness and covered with a substantial braid. It must not readily carry fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Farenheit, and three days' submersion in lime water, with a current of 550 volts after three minutes' electrification, and must *also* withstand a satisfactory test against such chemical compounds or mixtures as it will be liable to be subjected to in the risk under consideration.

RULE 22. INTERIOR CONDUITS :

The American Circular Loom Co. Tube, the *brass-sheathed* and the *iron-armored* tubes made by the Interior Conduit and Insulation Company, and the Vulca Tube are approved

WIRING RULES AND REQUIREMENTS.

NOTE.—The use of two *standard* wires, either separate or twin conductor, in a straight conduit installation is approved in the *iron-armored* conduit of the Interior Conduit and Insulation Company, but not in any of the other approved conduits. Rule 22. *e.*) (*See Addenda*).)

RULE 23. DOUBLE POLE SAFETY CUT-OUTS:

Section *a*. To be *approved*, boxes must be constructed, and cut-outs arranged, whether in a box or not, so as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

RULE 27. FIXTURE WORK:

Section *a*. Insulating joints to be *approved* must be entirely made of material that will resist the action of illuminating gases, and will not give way or soften under the heat of an ordinary gas flame. They shall be so arranged that a deposit of moisture will not destroy the insulating effect, and shall have an insulating resistance of 250,000 ohms between the gas pipe attachments, and be sufficiently strong to resist the strain they will be liable to in attachment.

RULE 38. POWER STATIONS:

Section *a*. Automatic circuit breakers should be submitted for *approval* before being used.

RULE 44. STORAGE OR PRIMARY BATTERIES:

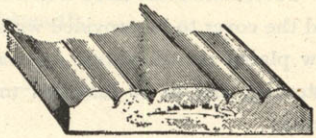
Section *b*. Insulators for mounting secondary batteries to be *approved* must be non-combustible, such as glass, or thorougly vitrified and glazed porcelain.

INSIDE WIRING.

FIG. 180.

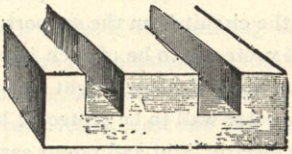
COVERED WIRE.

FIG. 181.



CLEAT COVER.

FIG. 182.



CLEAT.

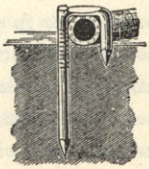
FIG. 183.

FIG. 184.

FIG. 185.

DOUBLE-POINTED TACKS.

FIG. 186.



NATIONAL BOARD FIRE UNDERWRITERS.

RULE 45. WIRE PROTECTORS:

Protectors must have a non-combustible, insulating base, and the cover to be provided with a lock similar to the lock now placed on telephone apparatus or some equally secure fastening, and to be installed under the following requirements:

1. The protector to be located at the point where the wires enter the building, either immediately inside or outside of the same. If outside, the protector to be inclosed in a metallic waterproof case.

2. If the protector is placed inside of building, the wires of the circuit from the support outside to the binding posts of the protector to be of such insulation as is approved for service wires of electric light and power, and the holes through the outer wall to be protected by bushing the same as required for electric light and power service wires.

3. The wires from the point of entrance to the protector to be run in accordance with rules for high potential wires; *i. e.*, free of contact with building, and supported on non-combustible insulators.

4. The ground wire shall be insulated, not smaller than No. 16 B. & S. gauge. This ground wire shall be kept at least three (3) inches from all conductors, and shall never be secured by uninsulated, double-pointed tacks.

5. The ground wire shall be attached to a water pipe, if possible; otherwise may be attached to a gas pipe. The ground wire shall be carried to and attached to the pipe outside of the first joint or coupling inside the foundation walls, and the connection shall be made by soldering, if

possible. In the absence of other good ground, the ground shall be made by means of a metallic plate or a bunch of wires buried in a permanently moist earth.

Addenda.

In addition to the foregoing Rules and Requirements, the *New York Board of Fire Underwriters* will require as follows:

UNDERGROUND CONDUCTORS: (See Rule 16.)

Must end outside of the main walls of the building and not be brought into a building where it is possible to avoid it; and when brought into the building, or any vault or area connected with same, must be removed at least *two* feet from all combustible material and kept free and clear of contact with any conducting material.

RULE 22. INTERIOR CONDUITS:

e. Must not be supplied with a twin conductor, or two separate conductors, in a single tube, unless the said two separate conductors, or twin conductor having an approved insulation, are enclosed in a complete, fully insulated, continuous iron conduit, and are in circuits installed as per table of Capacity of Wires (see Rule 25) for currents not to exceed 100 amperes.

The Rules and Regulations of the Board of Electrical Control and all existing regulations of The Local Authorities in reference to the stringing of wires, must be strictly observed.

NATIONAL BOARD FIRE UNDERWRITERS.

CENTRAL STATIONS—TESTING :

Companies furnishing electricity from Central Stations must enter into an agreement with the New York Board of Fire Underwriters, binding themselves to test their lines for ground connections at least *once* every day (and preferably three times per day), and report the result of such test to the Board weekly.

ELECTRIC LIGHTS AND MOTORS IN GENERAL STORAGE STORES :

Incandescent electric lights may be permitted when the entire plant is in full compliance with the rules of the Board, and an approved device, working automatically, is provided to cut out of building all the electric current when any excessive load is developed from any cause, and a certificate is issued to that effect ; provided the warehousemen will agree, in writing, to discontinue the use of lanterns and use no other lights (except in office) than the fixed incandescent lights that may be approved, and not to permit any alterations to be made in the electric plant after the certificate is issued, without the written consent of this Board ; it being understood that in case the electric plant is unable to run by reason of breakdown or accident, then lanterns as provided for in rules for Storage Stores may be used.

Electric power will be permitted for hoisting only, when the wires and motor are fully protected from contact with goods on storage and are placed as may be previously agreed upon with this Board, and a certificate issued that all is in full compliance with the Rules and Regulations of the Board.

WIRING RULES AND REQUIREMENTS.

Electric Heating and Cooking Apparatus; also Glue Pots, Sad Irons, Curling Irons, Etc.

ELECTRIC HEATERS, RANGES AND STOVES:

a. These must be placed in safe situations (out of easy reach of inflammable materials) and separated from and supported on non-conducting and incombustible standards or bases so as to be at least four inches from woodwork of any description or other inflammable material, unless protected by non-combustible materials such as sheet metal and asbestos, or the like, so combined as to prevent appreciable transmission of heat, while securing full insulation. The heating wires or resistances of these heaters, etc., must be inclosed in non-combustible cases adapted to prevent accidental contact with any exterior object or material. These electric Heaters, Stoves, etc., must never be concealed, but must be at all times in plain sight.

b. They must have double pole switches, cut-outs, etc., arranged as required for electric lights or power apparatus employing the same current and potential.

c. The attachment of feed-wires to "heaters," etc., must be in plain sight, easily accessible and protected from interference, accidental or otherwise.

d. Attachment of conductors to "heaters," etc., must be securely made in the same manner that conductors are attached to motors or generators dealing with currents equal to those employed in these devices, and such conductors must be continuous from the "heater" etc., to the switch or

NATIONAL BOARD FIRE UNDERWRITERS.

cut-out, which must not be within two feet of said "heaters" etc. These conductors must be thoroughly well insulated and also covered with a good mechanical protection.

PORTABLE COOKING APPARATUS, GLUE POTS, CURLING IRONS, ET

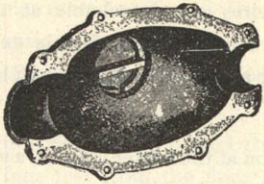
a. The heating coils or resistances of these instruments must be inclosed in non-combustible cases, which in turn must be mounted on non-conducting and incombustible bases raising the same at least one inch from any surface on which they stand.

b. These instruments must not be attached to lamp sockets, and when current of more than ten amperes is required they must conform to the same rules as Heaters, Ranges, etc.

c. Where currents of ten amperes or less are required, these instruments may be connected by specifically approved flexible double or twin-wire conductors, provided such conductor is composed of two multi-strand conductors, each of which is insulated by a waterproof material and asbestos while both are surrounded by a covering affording adequate mechanical protection. These flexible cords must also be connected to "plug switches" having double-pole fuses in their sockets which will cut out the circuits if a cross connection should occur in the flexible conductor. Moreover, such "plug switch" must be so arranged that the plug will pull out and break the connection if an abnormal mechanical strain is brought on the flexible conductor.

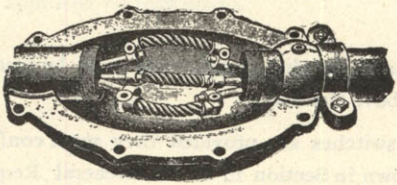
EDISON CONDUIT JUNCTION BOX

FIG. 187.



COVER.

FIG. 188.



OPEN.

FIG. 189.

CLOSED.

WIRING RULES AND REQUIREMENTS.

The leading-in wires of these flexible cords must be connected to heaters or the like at the point of lowest temperature, and where such wires are detachable at the heater, their terminals must be arranged with female ends protected by porcelain extending at least one-eighth inch beyond the metal terminals.

If the connection at the heater is fixed, a separable double-pole connector must be placed in the circuit so that in case an undue strain is brought on the conductors the device will be automatically cut out and disconnected.

Flexible cord connections longer than six feet will not be permitted.

Receptacles for plug attachments must be placed at least six inches above the floor.

Where switches are provided they must conform to the rules laid down in Section 26 of the General Requirements.

Where a number of utensils are grouped for general cooking service, installations to be approved must be provided with slate, soapstone or other approved slab or table for utensils to rest upon. Plug receptacles mounted on slate or other approved material shall be attached to mains running at least six inches above the working surface of the table.

Sad irons and other heating appliances that are intended to be applied to inflammable articles, such as clothing, must be arranged as above as far as connections, etc., are concealed and must also be provided with approved attachments which will cut off current when they are not in actual use.

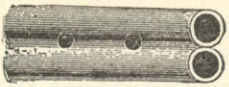
NATIONAL BOARD FIRE UNDERWRITERS.

The leading-in wires to these forms of apparatus must be connected through porcelain connecting blocks, and the cable or cord of the same must be passed through an insulated elastic spiral or spring so arranged as to protect the same from kinking, chafing or like injury at or near the point of conuection.

These conductors must be so placed that they will at all times be at least four feet from the floor and well protected against contact with water pipes or other possible ground connections.

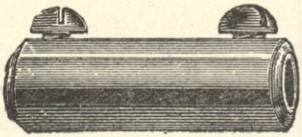
The use of no flexible cord will be permitted, unless specifically approved by this Board.

FIG. 190.



CONNECTORS.

FIG. 191.

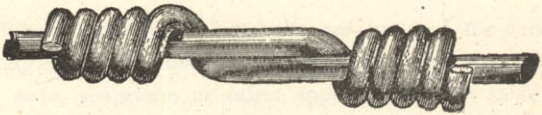


CONNECTORS FOR LINE WORK.

FIG. 192.

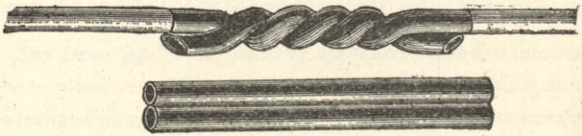
SLEEVE.

FIG. 193.



WESTERN UNION WIRE JOINT.

FIG. 194.



McINTIRE SLEEVE AND JOINT.

WIRING.

Wire Gauges.—In practice sizes of wires or conductors are designated in two ways : first, by measurements in 1,oooth of an inch, and, secondly, by the number of circular mils they contain, a circular mil being a circle one one-thousands of an inch in diameter, and the number of these circles contained in a cross section of a piece of wire is called a size of so many circular mils of cross section, or so many circular mils wire, the other being mils diameter. A copper bar one square inch in size, contains 1,273,200 circular mils, and a round wire, one inch in diameter contains exactly one million circular mils.

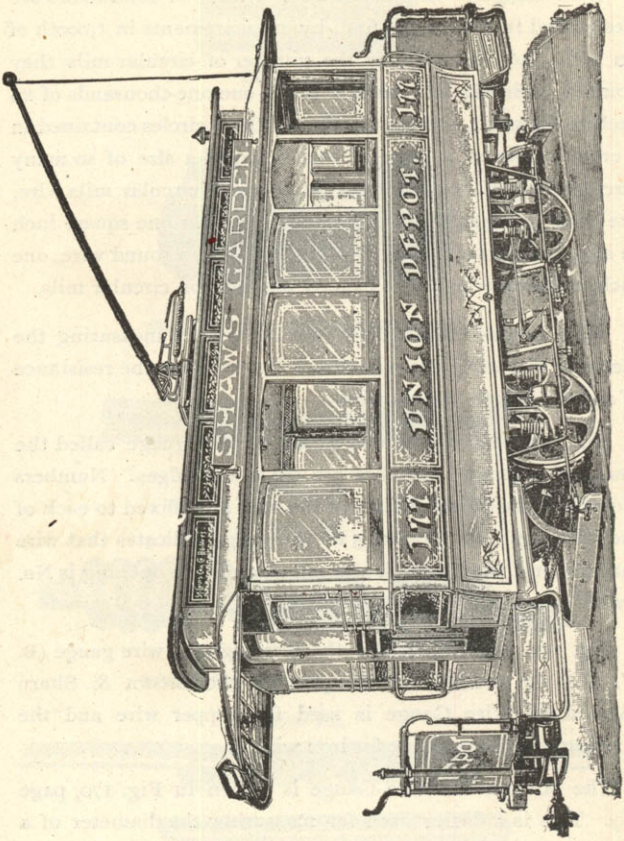
Wire gauges are employed for accurately measuring the diameter of a wire, this is done so as to calculate the resistance of a given length of such wire.

Fig. 172, page 391, shows a form of wire guage called the round wire gauge. Notches are cut in the edges. Numbers indicating the different sizes of the wire are affixed to each of the openings ; the number 5 in the gauge indicates that wire that will just pass through straight sides of the opening is No. 5 wire Brown & Sharp gauge (B. & S. G.)

Fig. 171, page 385, shows the Birmingham wire gauge (B. W. G.) In general electric practice the Brown & Sharp (American) Wire Gauge is used for copper wire and the Birmingham Wire Gauge for iron wire.

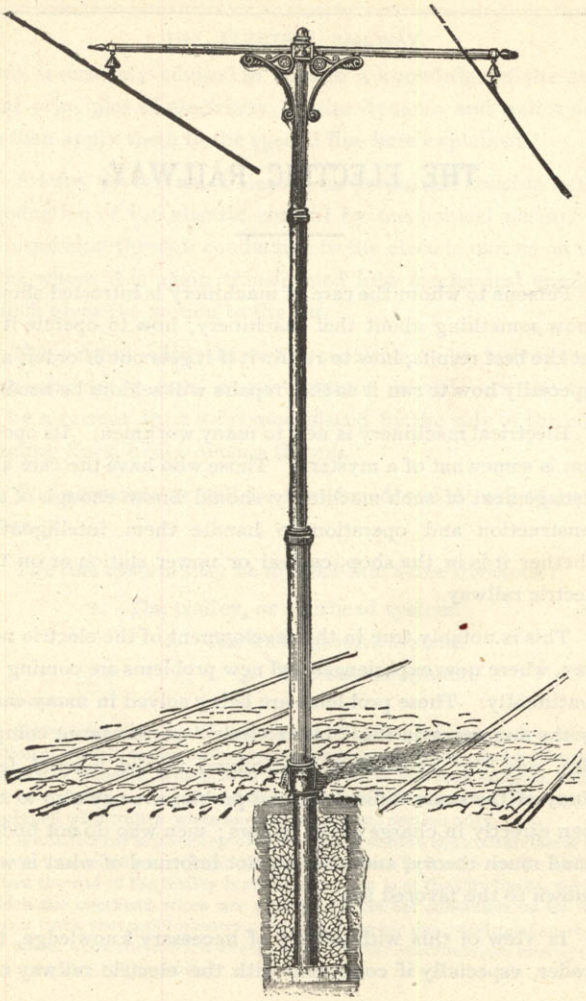
The Micrometer Wire Gauge is shown in Fig. 170, page 379. This is a device used for measuring the diameter of a wire in the thousandths of an inch. Micro as a prefix denotes the millionth part.

FIG. 195.



MODEL TROLLEY CAR.

FIG. 196.



ORNAMENTAL POLE, CONNECTIONS AND FOUNDATIONS.

THE ELECTRIC RAILWAY.

Persons to whom the care of machinery is intrusted should know something about that machinery, how to operate it to get the best results, how to repair it if it gets out of order, and especially how to run it so that repairs will seldom be needed.

Electrical machinery is new to many workmen. Its operation is somewhat of a mystery. Those who have the care and management of such machinery should know enough of the construction and operation to handle them intelligently, whether it is in the shop, central or power station or on the electric railway.

This is notably true in the development of the electric railway, where new experiences and new problems are coming up continually. These problems are being solved in many cases by the engineers in the "inner circle" of the large companies, and the knowledge is confined to the favored few. Many of the same difficulties and problems come also to the men directly in charge of the motors; men who do not understand much theory, and who are not informed of what is well known to the favored few.

In view of this withholding of necessary knowledge, the reader, especially if connected with the electric railway ser-

THE ELECTRIC RAILWAY.

vice, is seriously advised to acquire a knowledge of the general principles of electricity, of the dynamo and motor and to then apply them to the special line here explained.

Briefly, the system of electric car propulsion consists in the production of the electric current by mechanical means, its transmission through conductors to the electric motors on the cars, where it is again transformed into mechanical energy, which gives the motion to the car.

The current which drives the motors may be derived from two sources: 1, from an accumulator carried with the car; 2, by a current from a dynamo placed by the side of the conducting lines, hence outside the car.

The accumulator will be mentioned and described hereafter.

The line system may be divided into three divisions:

1. The trolley, or overhead system.
2. The underground system.
3. The surface system.

NOTE.—A novel plan of making use of both these systems is a combination of electric trolley and storage battery in operation upon a suburban railway in Hanover, where, after a long trial, it has been adopted. Electric accumulators are placed beneath the seats of the cars. The road is equipped with trolley wires and motors on one section only.

While the car is traveling over the trolley section the accumulators are charged, receiving a current through the same feed wire as the trolley. When the end of the trolley is reached, which is at the city limits, within which the overhead wires are prohibited, the car continues on its way over a track that was formerly used as a horse car line, relying absolutely for power upon the electric energy stored in the accumulators during the trip over the trolley road.

THE ELECTRIC RAILWAY.

The surface system (3) which is not much used consists in an arrangement where the iron or steel tracks are used for conductors.

The underground system (2) is still somewhat in an experimental stage. It calls for the use of underground "conduits" very similar to those in use in connection with the cable-car system of propulsion—but,

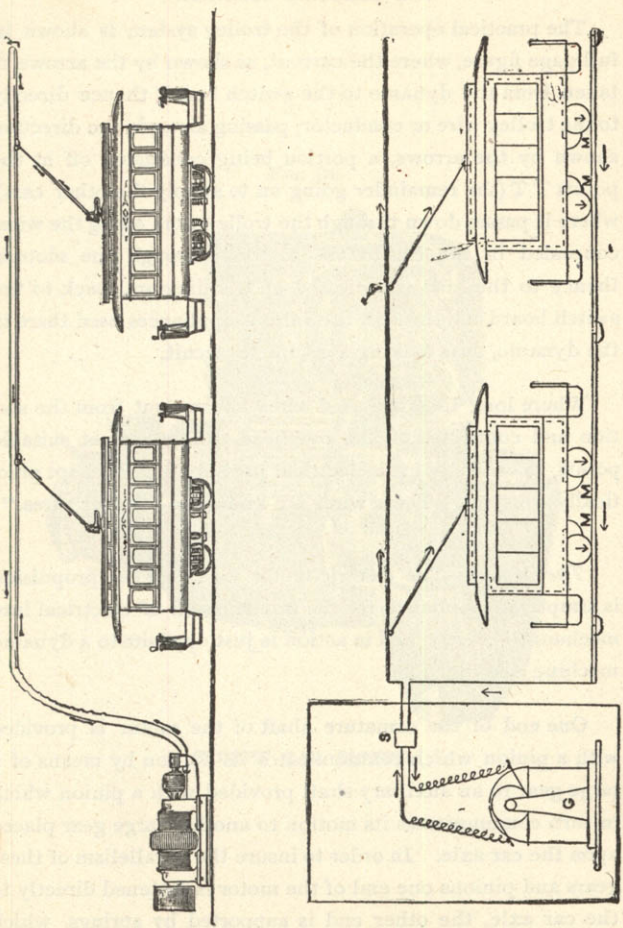
Conduits themselves are exceedingly expensive to construct, and cannot be operated unless there is a system of sewerage in connection with them, and in case of damage are exceedingly difficult to repair.

Hence the system known as the "Trolley" line has come into such general favor that nearly one thousand million dollars have already been invested in the system in the United States alone.

The Trolley Wheel is represented in Fig. 239; there are various forms of it, but usually they are made of brass, about five inches in diameter, mounted on the end of a pole about 12 feet long, bent over as shown in Figs. 195 and 197. The end of this pole sets in a frame attached to the car roof, and springs acting on the lower end press the wheel against the trolley wire. The pole may be of wood or steel.

The action of the wheel is such that it does not increase the sag of the wire but tends to push it up a little in its passage.

FIG. 197



OVERHEAD TRANSMISSION.

THE ELECTRIC RAILWAY.

The practical operation of the trolley system is shown in full page figure, where the current, as shown by the arrows, is taken from the dynamo to the switch board, thence directly to the trolley wire or conductor, passing along in the direction shown by the arrows, a portion being conducted off at the points T T (the remainder going on to supply the other cars), where it passes down through the trolley arm, along the wires concealed in the car to the motors, through the motors, thence to the rails as indicated on the diagram, back to the switch board and through the various appliances used there to the dynamo, thus making a complete circuit.

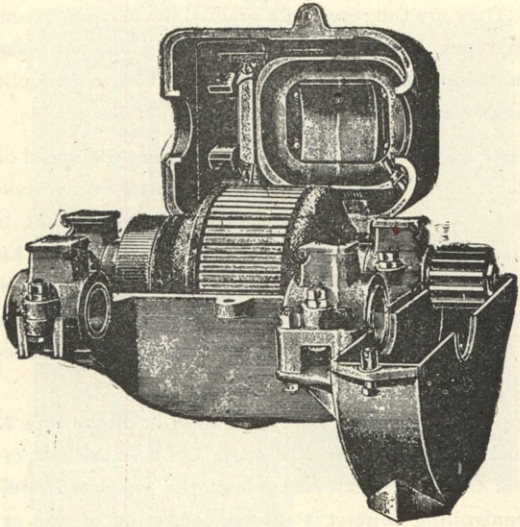
Where long lines are used wires are run out from the station and connected to the overhead trolley wire at suitable points, in order that the electrical pressure may be kept practically constant. These wires are known as "feeder wires."

The Motor.—The electric motor for street car propulsion is simply an appliance for the transmission of electrical into mechanical energy, and in action is just opposite to a dynamo machine (see Fig. 198).

One end of the armature shaft of the motor is provided with a pinion which communicates its motion by means of a large gear to an auxiliary shaft provided with a pinion which in turn communicates its motion to another large gear placed upon the car axle. In order to insure the parallelism of these gears and pinions one end of the motor is fastened directly to the car axle, the other end is supported by springs, which

THE ELECTRIC RAILWAY.

FIG. 198.



STREET CAR MOTOR.

permits of a movement of the motor and does away with the jar and strain which would otherwise occur on the starting and stopping of the car.

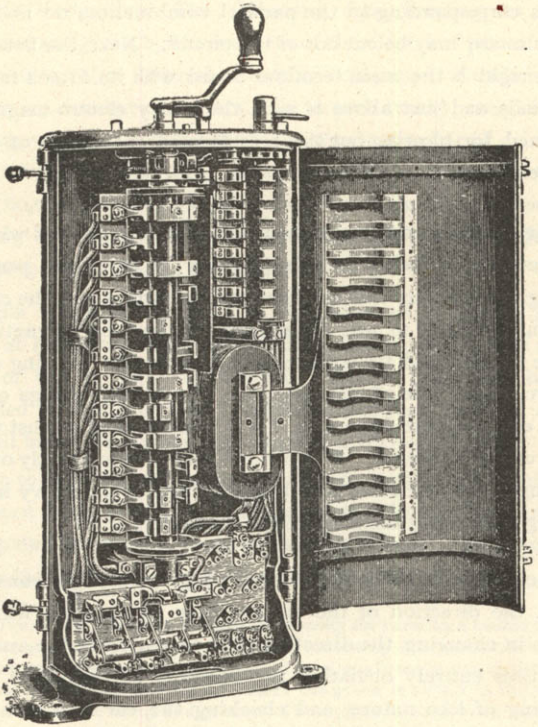
The Railway Motor Controllers now in use are in many respects, the most perfect devices ever employed for the purpose. They are the result of a gradual development from the earliest types, and in details of construction, perfection of workmanship and certainty of action they are undoubtedly enormously superior to all of the original styles.

There are several methods of governing the speed of the electric motor. In some systems a rheostat or resistance is connected in series with the armature, this rheostat being governed by mechanism placed at each end of the car, known as the "controller stand." This controller stand is provided with a handle, by means of which the amount of current which flows through the motor and the speed may be easily regulated.

Fig. 199 shows very clearly the interior of the type K2 as now made by the General Electric Co. At the left of the center of the figure, extending from the top downward, the main controlling contact is shown, consisting of arcs or segments of circles, each of which terminates in a removable copper contact tip. The twelve contact fingers are shown at the left. Above, at the right, are shown the eight fingers and contacts of the reversing cylinder.

Near the bottom of the controller at the left are the two cut-out handles, the raising of which cuts out either No. 1 or

FIG. 199.



RAILWAY MOTOR CONTROLLER.

No. 2 motor as may be desired, at the same time locking the main controlling drum so that it can not be turned to the points corresponding to the parallel combination, no matter which motor may be cut out of the circuit. Near the bottom at the right is the main terminal board with its fifteen main terminals and just above is seen the heavy electro-magnet, designed for blowing out the arcs formed at the tips of the contact fingers.

The magnet is connected in on the main circuit, and whatever current is being used by the car at any time passes through its coil, so that the heavier the current and the consequent tendency to arc, the stronger is the field magnetism of the magnet and its corresponding power for blowing out the arc. One pole of the magnet is hinged and swings outward, exposing the fingers, as it is shown outlined against the cover of the controller. When closed this pole is directly over the finger tips, the other pole being formed by the heavy iron casting composing the back of the controller.

Each car is provided with a revervsing switch, by means of which the direction of the current may be changed, which results in changing the direction of the rotation of the armature, thus entirely obviating the necessity of turntables, or anything of like nature, and checking the car in a case of great emergency to avoid accident or collision. Each car is also provided with lightning arresters embodying the same principles as those used in the power station, by means of which all danger from lightning discharges is obviated.

THE ELECTRIC RAILWAY.

The Electric Locomotive.—The most interesting development of the overhead (trolley) system is, of course, the 96-ton electric locomotive. The following data, relating to the machine are given by the builders of the electrical part of the locomotive, the General Electric Company: Number of trucks, 2; number of motors, 4 (2 to each truck); weight on driving wheels, 192,000 pounds (96 tons); number of driving wheels, 8; drawbar pull, 42,000 pounds; starting drawbar pull, 60,000 pounds; gauge, 4 feet 8½ inches; diameter of drivers, 62 inches outside of tires; length over all, 35 feet; height to top of cab, 14 feet 3 inches.

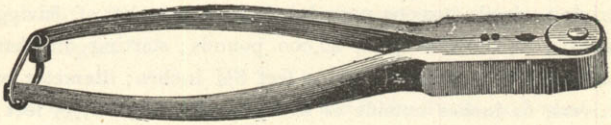
This machine has been in operation since August 4th, 1895, at Baltimore, hauling the entire northbound freight service of the B. and O. railroad. Every train has been handled promptly and the locomotive has been ready at any and all hours during the day, causing no delay to traffic.

Up to the present time no train which would hold together has been found heavy enough to cause the electric locomotive to slip its wheels under ordinary fair conditions. The capacity of the locomotive has been by no means reached.

NOTE.—Test was made to learn its capacity for running a loaded train on an up grade. For this purpose a train consisting of two steam locomotives, not working, and 27 loaded freight cars, was brought to a stop while going north through the tunnel. Here the grade is 42 feet to the mile, and the rails were damp and greasy. The weight of the train alone was 1125 tons, or 1221 including the electric locomotive. Every drawbar was tight, no slack occurring throughout the the length of the train. In this condition current was turned into the motors and movement was immediately communicated to the train. At the end of one minute the train was moving at a speed of ten and one-half miles an hour, and at this point the speed was increased to the usual rate.

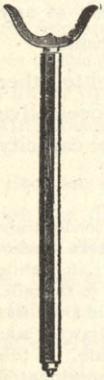
LINEMEN'S CONSTRUCTION TOOLS.

FIG. 200.



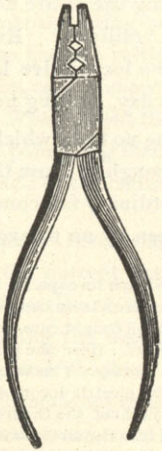
CONNECTORS.

FIG. 201.



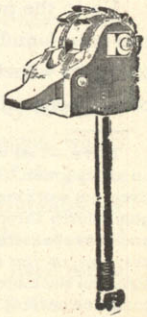
POLE SUPPORT.

FIG. 202.



CONNECTORS.

FIG. 203.



POLE RATCHET.

LINE WORK.

Instructions and Cautions for Linemen.—When cutting wire, grip the line with the cutting jaws of the pliers and move up and down at right angles with the wire two or three times, so that you cut the insolation part of the way round on both sides; then hold your pliers firmly, bend the wire once or twice up and down with your left hand and the wire will break. Never try to break the wire by twisting your pliers, unless you first move the line out of the cutting jaws. There is no excuse for nicks in the cutting jaws of Stub's pliers, and careful linemen rarely have it happen.

In stripping the ends of wire to make a connection, always cut along the wire towards the end, in much the same manner as if whittling a stick. Never cut round the wire with the edge of the knife or pliers, except when cutting the wire.

In making joints, be careful never to let the cutting jaws or edge of your tools "score" the wire. If you do, don't cover it up, but make a new joint.

After a joint is made with not less than four turns each side of the connectors, dip or moisten with acid. If you are on the ground, dip the joint in melted solder and hold it there a few seconds to thoroughly heat the joint, then take it out. If well "tinned," dip it in water to remove any acid which may be on the ends of the wire near the insulation.

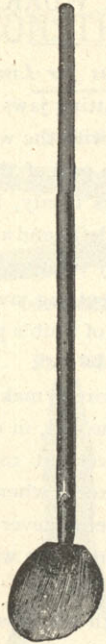
NOTE.—For very much of the following pages relating to practical electric railroading we are indebted to Jas. I. Ayer, General Manager, St. Louis, Mo.

LINEMAN'S CONSTRUCTION TOOLS.

FIG. 204.

DIGGING SHOVEL.

FIG. 205.



SPOON SHOVEL.

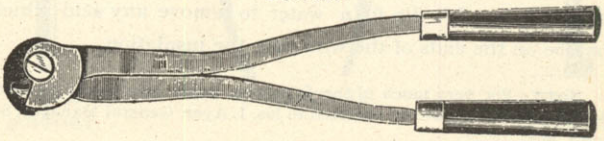
FIG. 206.

TAMPING BAR.

FIG. 207

DIGGING BAR.

FIG. 208.



SAFETY WIRE CUTTERS.

LINE WORK.

If where you cannot dip the joint, but have to use the ladle, pour the solder frequently over the joint until it leaves a thin, smooth coating on the wire. It is not properly done if the solder is in lumps or on in a thick layer.

If you are obliged to use a "blow pot," hold the joint in the flame until the solder will easily melt when held against the wire after the flame is removed. When this is accomplished, apply the solder with the flame, and not before.

Solder is put on the joints to keep them from corroding, thereby insuring good contact where the two wires come together, and is of no use if not well applied.

After the joint is well cleaned of acid after being soldered, paint it thoroughly with insulating compound, then cover with a layer of tape, which you will start on one side of the joint, against the insulation of the wire, but not over it. Have the first layer cover the joint and bare wire only. When this is done, paint it, then start back over the joint and tape until you have run over the line insulation about two inches, then wrap two more layers, painting each when done.

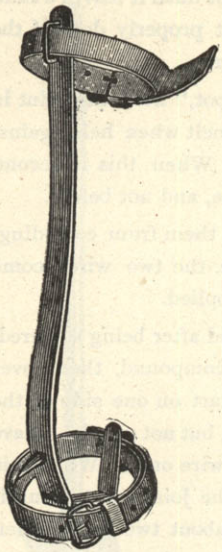
In wrapping tape, cover what you have half, or lap one-half. After four layers are on, paint the whole thoroughly.

Whenever you find a break in the insulation on the line anywhere, paint it first, then tape and paint it. Don't forget this.

In "tying in," never draw the tie wire so as to bend a kink in the line or cut through the insulation with the tie. A tie will properly hold the wire in place without drawing it so tight as to do either.

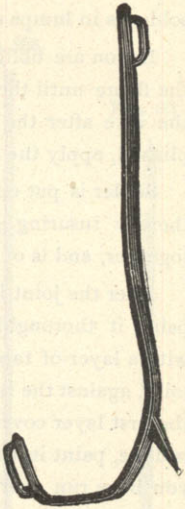
LINEMAN'S CONSTRUCTION TOOLS.

FIG. 209.



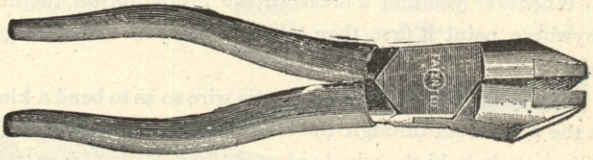
"CLIMBERS."

FIG. 210.



"CLIMBERS."

FIG. 211.



LINEMAN'S PLIERS.

LINE WORK.

In using pulley blocks on the line, avoid the use of "come-alongs" when possible, by taking a series of half-hitches, or making a "noose wrap" with a small line on the wire to hook the block to. If you do use "come-alongs," see that you do not score, cut or kink the wire, and always paint and tape broken insulation.

Groundmen are especially cautioned to watch the line in "paying out" and prevent "kinking." Should a short kink get pulled into the line, cut it out rather than take the risk of its breaking, though you should straighten it out.

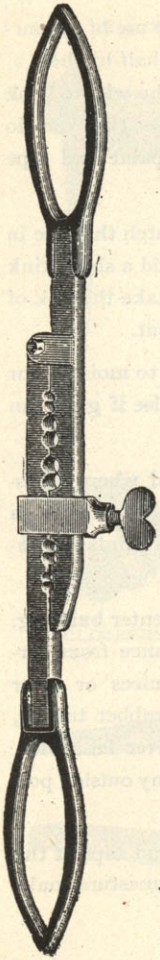
Never use porcelain knobs where exposed to moisture or the weather, and never use them anywhere else if glass can possibly be used.

Porcelain knobs circuit breaks may be used where necessary, providing not more than two lamps are on the loop. In making them, paint and insulate with tape the joints in connecting wire of loop.

In making house connections where wires enter building, be sure to have not less than six inches clearance from cornices of walls. All wiring running over cornices or other building projections must be protected with rubber tubing, thoroughly taped and painted at the end. Never let a wire, however well protected, come in contact with any outside portion of the building.

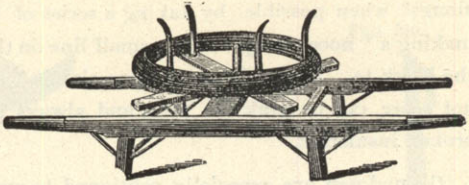
In placing tubing on wire, carefully paint and tape at the upper end, leaving the lower end open, so that moisture could escape if it got in.

FIG. 212



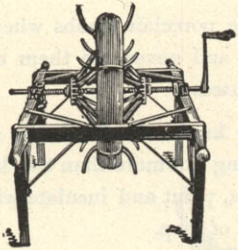
LINEMAN'S TOOLS

FIG. 213.



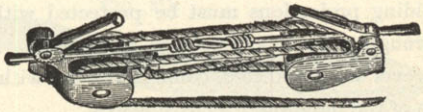
REEL AND STAND.

FIG. 214.



REEL AND STAND.

FIG. 215.



BLOCK AND FALLS WITH "COME-ALONGS."

MCINTIRE SPLICING TOOL (FIG. 212)

LINE WORK.

Always run wires in straight parallel lines, and make square turns where possible. Twelve inches between wires is the proper space for arc lighting circuits, where practicable.

Never fasten a cut-out box against the wall. Always place glass or porcelain knobs between the box and the wall.

Never fail to put in "drip-loops" in line where entering building.

In all electrical work, remember where insulation is desired it can never be too good, or when contact is desired, you can never make it too good or strong.

In removing lamps ordered out, always close the loop at the line where it was originally cut in, and remove all dead wire. Never leave dead or unnecessary wire in circuit.

Always use iron pins on arms where wires turn a corner or leave the line.

Never screw an insulator on iron pin or bracket very tight, nor without first putting inside the glass a strip of paper folded twice or three times. This will prevent the glass being broken, as iron expands with heat nearly twice as rapidly as glass, and unless there is room enough, the difference in temperature between winter and summer would burst insulators in summer which were placed in winter.

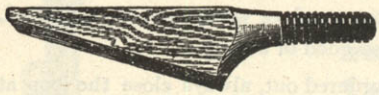
In connecting line to lamps hung from suspension wire, put on safety loops by making a half-connection with a short flexible wire on each side of the insulators at the pole and on the lamp hood. Solder and tape same as other joints. Arrange the length of wires leading to lamp, so the lamp will not shadow the roadway of either street.

LINE APPLIANCES.

FIG. 216.

WOOD PIN.

FIG. 217.

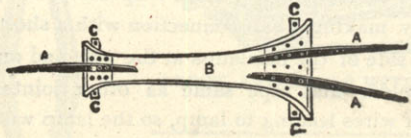


WOOD BRACKET.

FIG. 218.

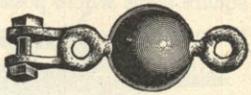
THREE POINT FROG.

FIG. 219.



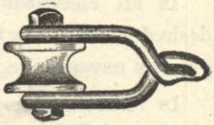
TROLLEY FROG.

FIG. 220.



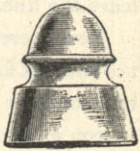
GLOBE INSULATOR.

FIG. 221.



TREE INSULATOR.

FIG. 222.



INSULATOR.

FIG. 223.

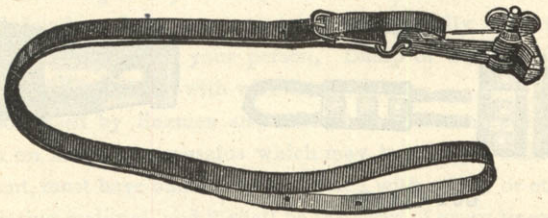
INSULATED PLUG.

INSTRUCTIONS AND CAUTIONS.

Do not handle any electric light apparatus while you are standing on the ground.

Never use both of your hands while handling dynamos, or anything pertaining to same, while said dynamos are being used.

FIG. 224.



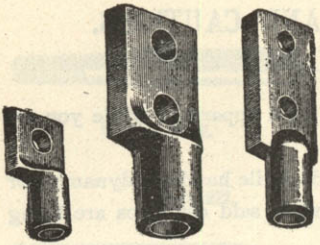
LINEMAN'S SAFETY BELT.

Do not touch a water pipe, iron post, or any stone, brick or iron structure while in contact with a lamp, line, dynamo, or anything connected with the electric light apparatus at the same time, unless you are provided with rubber gloves or other insulating material.

When your business necessitates your going through the station, keep as far as possible from the machinery and belting, and do not meddle with anything unless you are ordered by the man in charge, and then only after receiving careful instructions.

LINE APPLIANCES.

FIG. 225.

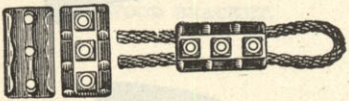


TERMINALS.

FIG. 226.

WIRE INSULATOR

FIG. 227.



GUY CLAMP.

FIG. 228.

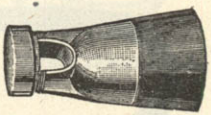


FIG. 229.

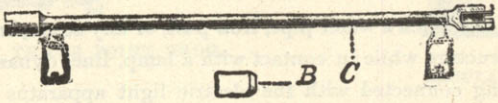
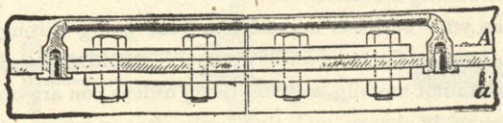


FIG. 230.



RAIL JOINTS.

LINE WORK.

No one is permitted to in any manner work on the switchboards except when directed so to do by the man in charge of dynamo room, and then only after receiving careful instructions.

Keep away from the lightning arresters and wires leading to them.

Linemen or others operating on lines, must handle each and every wire at all times as if it were charged with the electric lighting current and grounded.

When obliged to pass over, under, or by an electric wire, avoid touching it in any manner, and especially with any uncovered portion of your person. Damp or wet clothing makes chance contact with wire dangerous.

Tools used by linemen and others who have occasion to work on lamps or apparatus which may be charged with the current, must have handles well covered with rubber or other insulating material, and it shall be the duty of every lineman to look after his tools and see that they are in good condition for use, and especially as to the insulation of the handles.

If it is at any time necessary to stand on the ground or any surface not insulated from the ground while handling electric wires or apparatus, heavy gum boots or an insulated stool must be used; and under no circumstances allow yourself to make contact between two or more wires at the same time.

Lamp trimmers and others engaged in taking care of and trimming lamps, must see that the switch on the board from which the lamp hangs is closed before they proceed to handle the lamp. Instructions laid down in these rules must be observed in connection with the work of handling the lamps.

LINE APPLIANCES.

FIG. 231.

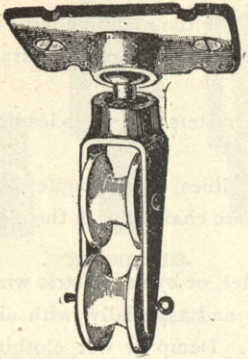


FIG. 232.

TREE INSULATORS.

FIG. 233.

FIG. 234.

FIG. 235.

FIG. 236.

FEEDER LINE "EARS."

LINE WORK.

In the event of any one in any manner being caught on live wires, where it is possible to get to them, pull the one caught away by grasping any portion of his clothing or body protected by clothing. There would be no possible danger to the one rendering help, no matter where you may be standing. If the one caught should be on a pole or ladder, he could usually release himself by kicking himself loose from the supports, or drawing up his knees, thereby causing the body to fall. It is understood that employees will wear and use their safety belts when working above ground on poles or ladders, especially when handling wires.

In working on lines, all circuits must at all times be regarded as alive and grounded. With the hundreds of miles of wire throughout the city, some of which are carrying heavy current at all times, many using ground return, the line you are on may "come alive" at any time—be careful.

Always avoid temporary work.

When working on poles, be careful to stand so, if you should slip or get a shock, you would fall on your belt rather than on the wires.

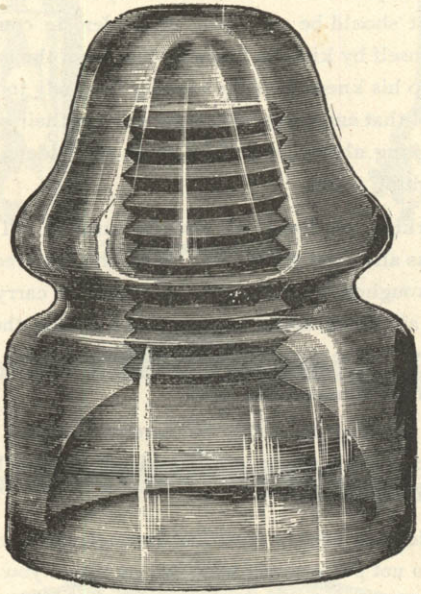
Avoid leaning over or crowding through wires when possible, and do not put yourself in a position where you would fall on wires, should an accident occur.

Always in making connection on poles, work from below rather than above, when possible.

Examine cross arms and see that they are sound and firmly fastened before trusting your weight on them.

LINE APPLIANCES.

FIG. 237.



GLASS INSULATOR.

LINE WORK.

Be careful that all tools are securely fastened in your belt when working pole or ladder, and, in handling wires and lines on poles, have a proper regard for the safety of those walking or driving below.

When working on poles, always use your safety belt, as well as other safety devices which you are requested to use. It takes but a little time to make yourself safe, and many weeks to mend a broken bone.

Never lay tools down when above the ground.

See that all wires leading out of transformers and out of fuse boxes are well taped and painted where they leave the transformers, and all transformers must be placed so far from doors, balconies, windows and other openings, and sufficiently high above ground and roof, as to prevent accidental contact, in other words, out of reach.

Instructions and Cautions for the Dynamo Room.—All station employees are requested to study the circuit maps and become familiar with the locations of the different circuits.

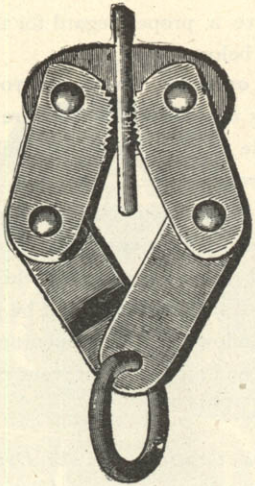
On receipt of telephone or other message to cut out any circuit for the protection of life and property, do so promptly. On an arc circuit, always run the brushes up before pulling plugs on switch-board. On incandescent by cutting in resistance at switch-board to kill the dynamo, then open the switch.

When a live circuit opens during a run, the dynamo must be cut out at once and left out until the trouble is located and O. K'd by lineman or inspector.

Circuits ordered open must be marked on board with colored chalk. All other circuits must be marked "O. K." with

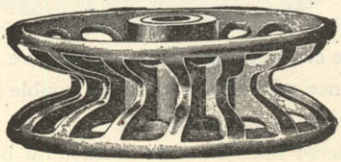
LINE APPLIANCES.

FIG. 238.



"COME-A-LONG."

FIG. 239.



TROLLEY WHEEL.

white chalk. This must be done only by those authorized so to do, and must be reported to man in charge in dynamo room.

Never "try" a circuit with dynamo that opens during a run, until the trouble is located, no matter if it "rings" closed.

Never connect dynamo to a circuit on which men are at work, without instructions from the men to do so.

When an arc light or motor circuit is reported "O. K." after it has been open, build up current very slowly at dynamo by hand, and take about five minutes to put full current on, because it frequently happens that linemen will leave their work and start out on a circuit looking for trouble, without first notifying the station. By starting the circuit in this manner, should they be in a position where they might feel the current, they would likely have warning before current reached a dangerous intensity.

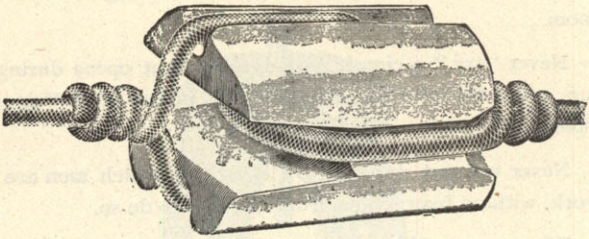
Never run two machines in series. Doing this will be sufficient cause for dismissal. No excuse will be accepted for disobedience of this rule.

Rubber mats and gloves must be used when working the switch-board. The same rule applies to work on dynamos when running.

An arc made by electricity can frequently be blown or whipped out with a towel, on continuous current circuits, and should be extinguished in that manner, if the connections which occasion the arc cannot be easily separated.

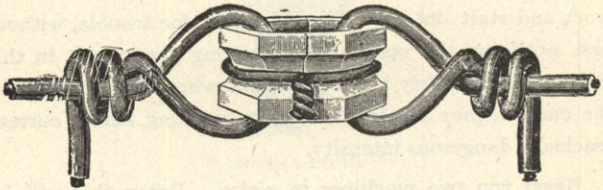
LINE APPLIANCES.

FIG. 240.



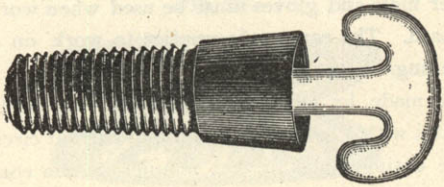
CIRCUIT BREAKER.

FIG. 241.



CIRCUIT BREAKER.

FIG. 242.



RUBBER HOOK INSULATOR.

LINE WORK.

In the event of a short circuit on alternating lines or switches in station, the current can be safely shut off by cutting in resistance on exciter at switch-board.

Water will not extinguish an electric arc or fire when produced only by the current.

Large canvas covers are available, which should be quickly spread over the dynamos if water is used to extinguish fire on the floor above.

Fire buckets must be kept filled with both sand and water on each floor in machine building above engine room. In many cases sand will prove more useful than water in extinguishing a fire. The hose on each floor must be kept connected and ready for use.

In using sand or water, remember that a little well directed is better than quantities thrown wildly. Use no more of either than is absolutely necessary, as it is easy to do more damage with them than would be likely by fire.

Any faulty lamps, wires, belts or anything else reported to this department, must have immediate attention from the man in charge.

No joints are permitted to be made and left without being soldered.

When placing guard wires on street crossings, always use iron pins and glass insulators to attach both ends of guard wires to. Never tie on cross arm pole. In stormy weather, when they may be of use, they would be dangerous every way.

LINE WORK.

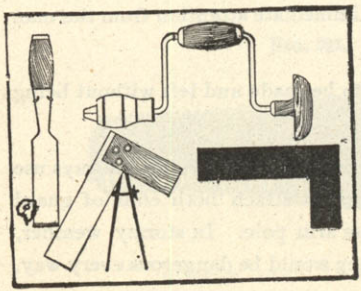
Location of Trolley Wire.—On straight line work the wire should be over the center of the track.

At curves the wire should be placed on the inside of the curve, its distance from the center of the track depending on the degree of curvature.

The Repair Shop.—Near the car house, if not under the same roof, should be placed the shop for such repairing as is profitable for the company to do themselves. The few tools—a lathe, drill press, etc.—may be conveniently run by a stationary electric motor.

In the repair shops, perhaps even more than other parts of the plant, order and neatness should be the rule. The armatures should be kept in racks and not on the floors. The winders and their supply of wire should be kept away from litter of any kind. The floor should be well swept especially of all metal filings. Each kind of supply should have a special bin, etc., etc.

FIG. 253.



In Fig. 253 is contained a suggestion. As each tool should have a place it is well, if convenient, to have a little "silhouette" drawing made just under the place a tool should be hanging. When the tool is away this is a reminder to put it back.

CARE AND MANAGEMENT OF THE STREET CAR MOTOR.

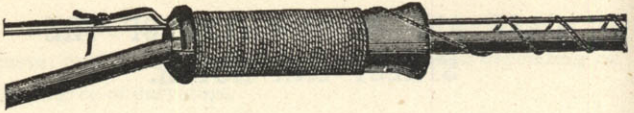
The motor should have exceptionally good care. This can only be given by frequent and careful inspection. The dynamo and engine in the power house are carefully watched and oiled. They are well located and have every advantage; on the same principle the street car motor needs very much more care, due to its unfavorable location.

Washers, carbon dust, bits of gravel, sand, pieces of carbon brushes, and other matter capable of doing serious damage, have been found in the motor cases of some of the best types. The time for inspection is usually brief, but everything must be noted. Spare parts should be at hand and no armature or field coil in which a defect is suspected to exist should be allowed to go on a trip.

Loose nuts, hot boxes, burnt commutator bars, and matters of a kindred nature, should be carefully sought for. Dust or mud should not be allowed to accumulate. The screws of the motor support should receive minute inspection. Every screw on the truck is liable to be jarred loose and the dropping of the motor into the street is almost certain to wreck the greater part of the equipment, both mechanically and electrically.

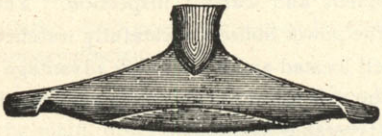
LINE APLIANCES.

FIG. 243.



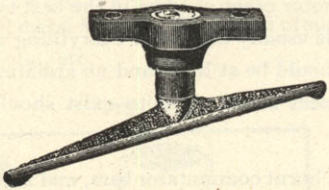
WINDING MACHINE.

FIG. 244.



MECHANICAL "CLIP."

FIG. 245.

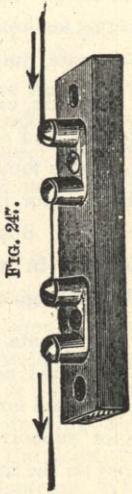


BARN OR BRIDGE HANGER.

FIG. 246.

TROLLEY CROSS-OVER.

FIG. 247.



FUSE AND CONNECTIONS.

CARE OF THE MOTOR.

The motorman should be present when his motor is taken apart and inspected. By this means he will become familiar with the various parts and their diseases. The motor is under his care the greater part of the time and therefore the more he knows of its construction the fewer accidents there will be.

The car should be provided with a monkey wrench, a few duplicates of the most important bolts and nuts, a pair of pliers, some rubber tape and a supply of insulated copper wire about No. 8 B. & S. With these simple tools and materials vexatious delays can often be avoided.

Run carefully over curves, crossings and switches and thus save both them and the motors.

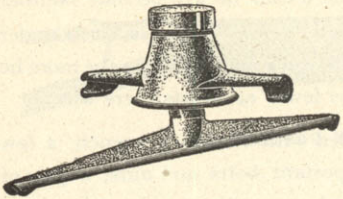
With a little practice the motorman can accustom himself to the ordinary sights, sounds and smells on and about a car equipment and anything unusual will at once be detected.

The one thiug that is most liable to derange the mechanical portion of a car equipmeut is vibration. This is largely met by a properly designed truck, but a careful motorman can also do much to reduce this evil.

Feeder Wires.—In electric railways the feeder wire supplies the current from the generator, to the trolley wires. In lighting systems it is the main wire coming from the dynamo. Feeder cables are always made of stranded—or more than one wire.

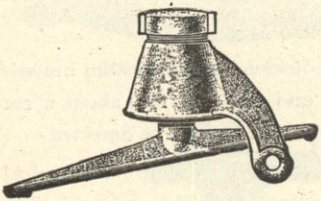
LINE APPLIANCES.

FIG. 248.



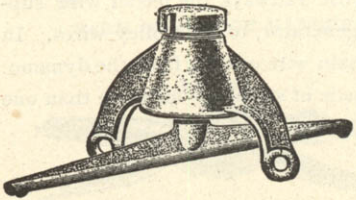
"HANGER" AND "EAR."

FIG. 249.



SINGLE "PULL-OFF" AND EAR.

FIG. 250.



DOUBLE "PULL-OFF" AND EAR.

FIG. 251.

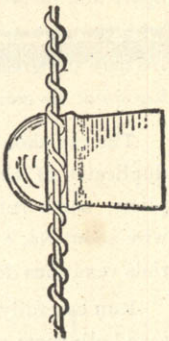
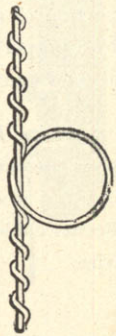


FIG. 252.



WIRE TIES.

STORAGE BATTERIES.

These are also known as accumulators from the fact that they accumulate or store electric energy ; they are also called secondary batteries in distinction to primary batteries described on page 47.

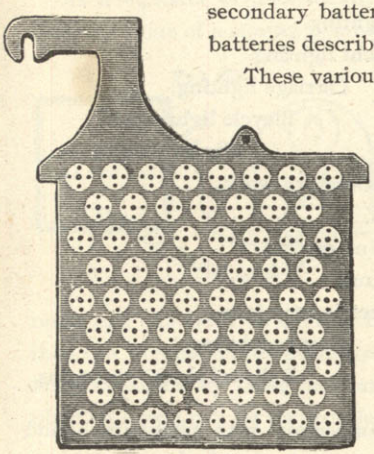


FIG. 254.

These various terms are applied either to a single cell or to a collection of cells electrically connected together.

Secondary batteries are in no sense generators of electricity but are employed to accumulate, or store, a given quantity of electric energy, the quantity of which is estimated by the numbers of hours required to discharge it at a given rate.

While the electric energy may be produced by a primary battery, it is usually stored by the use of a dynamo, as shown in Fig. 255.

During the "charging" process the electric energy is accumulated and during the discharge the chemical processes are reversed, the electric energy flowing from the battery until the materials are restored to their original chemical condition.

STORAGE BATTERIES.

Accumulators are coming into rapid application in many different ways. Following is a list of some, in which accumulators are giving highly satisfactory results:

Electric locomotives for hauling in factories and mines.
Carriage propulsion.
Electric launch propulsion.
Train lighting.
Yacht lighting.
Carriage lighting.
Bicycle lighting.
Miners' lamps.
Medical, surgical and laboratory work.
Phonographs.
Sewing machine motors.
Fan motors.
Electric fire-alarm.
Heat regulating.
Railroad signal apparatus.

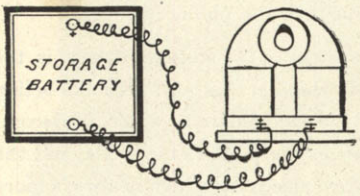
For portable use, in connection with phonograph and other small motor work and small electric lamps, chloride accumulators are put up in sealed rubber jars, enclosed in neat hardwood cases, provided with handles and binding posts. Various capacities are furnished for batteries complete, filled with acid, and charged up ready for immediate use.

But, it is in connection with electric railways and electric light and power companies that the greatest advances are being made; in Europe especially, great attention is being

paid to the subject; eight years' experience in German central station practice have indicated that the use of storage batteries insured a reduction of 33⅓ per cent. in the engine and boiler capacity and a saving of from 20 to 50 per cent. in the coal consumption of a station.

As a regulator of pressure, in case of fluctuations in the load, the value of a storing plant is inestimable. These fluctuations of load are particularly noticeable in electric railway plants, where the demand is constantly rising and falling, sometimes jumping from almost nothing to the maximum, and *vice versa*, in a few seconds. If for no other reason than the prevention of severe strain on the engines and generators, caused by these fluctuations of demand, a storage-plant will soon pay for its installation.

FIG. 255.



By the installing of a storage plant many natural but small sources of power may be utilized in furnishing light and power; sources which otherwise are not available, because not large enough to supply maximum demands. The force of the tides, of small water powers from irrigating ditches, and even of the wind, come under this heading.

One plant recently installed consists of a twenty-horse power engine, two hundred-light dynamo and a one hundred-

light battery. On special occasions, battery and dynamo working together will operate three hundred lights, but under ordinary conditions one hundred lights are all that are used. By running the engine twice, or at most three times a week, for a few hours at a time, the battery is kept properly charged, and the owner has ample light of the most satisfactory kind, obtainable at all times—day or night.

The Plantes Cell was the first practical storage battery constructed; it was introduced to the public in 1859.

Plante's theory of the system of the storage battery is the simplest one to understand, which is this: "Under the action of the primary current, the (accidulated) water is decomposed; the oxygen peroxidizes the positive electrode, and the hydrogen goes to the negative electrode, which is always more or less oxydized by the exposure of the air."

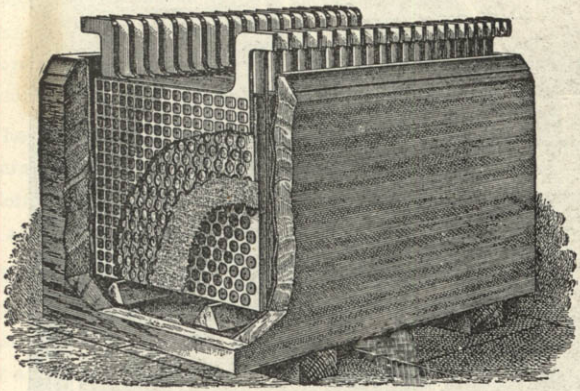
Undoubtedly many other changes take place, sufficient to make the action of a storage battery a mystery, but practically we have made no farther advance than the carrying out of Plante's theory to more practical and commercial results.

NOTE.—In all lead storage batteries, one of the objects desired is to obtain a large lead surface for small mass, as the capacity and discharge rates are strictly proportional to the amount of surface involved. This necessary maximum of surface has hitherto been obtained in one of two ways. The earlier way was to slowly eat out the lead plates by electrolysis until they had attained the requisite spongy condition, an affair of some time and expense. The later way—and the one which is generally practiced—is to cast a frame of lead, with raised right-angled ribs on each side, thus forming little depressed squares, or to punch a lead plate full of holes, which squares or holes are then filled with a pasty mixture of red oxide of lead in positive plates, and with litharge in negatives.

STORAGE BATTERIES.

The Faure Cell, so-called, marked the second step in advance; This was introduced in 1881. The improvement consisted in giving the two lead plates a preliminary coating of red lead.

FIG. 256.



In recent forms of accumulators the red lead or (lithage) freshly mixed with dilute sulphuric acid to the form of a paste is pressed into the holes of a *leaden grid* shaped so as to give it a good mechanical attachment.

Fig. 254 represents "the grid" which is not unlike the old fashioned "grid-iron."

The Chloride Accumulator is now being most successfully introduced owing greatly to the growing use of storage batteries in connection with electric light and power plants.

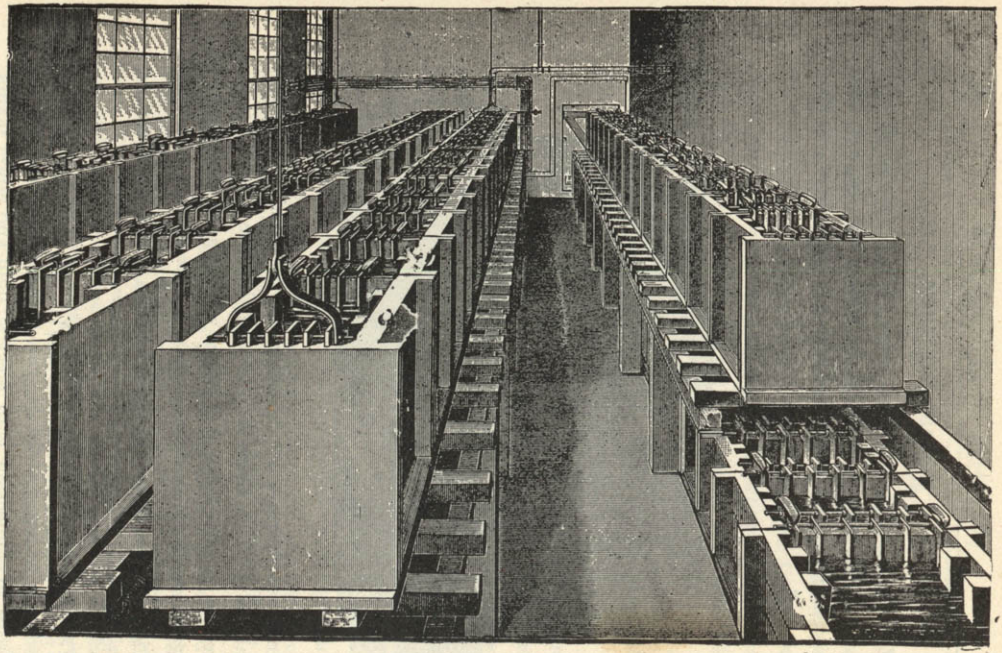


FIG. 257.

STORAGE BATTERIES.

Fig. 256 represents the lead lined wood tank in which the grids are arranged in symmetrical order as shown in the cut, full page, Fig. 257, illustrates the method of arrangement at the station of the Germantown Electric Light Co., of Philadelphia.

This battery consists of one hundred and twenty elements of eleven plates each. They are installed on the three-wire system, and have a normal discharge rate of one hundred amperes on each side, and a capacity at this rate of two thousand ampere hours.

The plates are protected by improved asbestos insulation, and are contained in lead-lined wooden tanks set on glass insulators, and supported on strong supporting stands, painted with acid-proof paint in four rows of two tiers each.

The special application of a battery in this instance is for the purpose of carrying the day load of the station for the commercial lighting and power circuit, and also at times to carry a portion of the night load. The engines are shut down at daylight and the battery carries the whole load until dusk, at which time it is thrown out of circuit. It is put into charge between midnight and 6 A. M., when the station load is small. The cost of charging is practically nothing, as the machinery is more efficient and no extra labor is required, while during discharge the working force of the station is considerably reduced, the battery requiring but slight attention.

It should always be remembered that we are not pouring something into a storage tank to be taken out when desired, as seems to be the opinion of some, but that a very sensitive process is being gone through that requires care in conducting.

Table Showing the Relative Dimensions of Pure Copper Wire at 60° Fahrenheit.

Number. B. W. G.	Diameter. Inch.	Area. Square Inches.	Weight and Length.	
			Lbs per 1000 ft.	Lbs. per mile 1760 yds.
0000	.454	.1618	623.92	3294.3
000	.425	.1419	546.76	2886.9
00	.380	.1134	437.10	2307.9
0	.34	.0908	349.93	1847.6
1	.300	.0707	272.43	1438.4
2	.284	.0633	244.15	1289.1
3	.259	.0527	203.06	1072.1
4	.238	.0445	171.46	905.3
5	.22	.0380	146.51	773.6
6	.203	.0324	124.74	658.6
7	.18	.0254	98.09	517.8
8	.165	.0214	82.41	435.1
9	.148	.0172	66.30	550.1
10	.134	.0141	54.35	287.0
11	.120	.0113	43.59	230.1
12	.109	.0093	35.96	189.9
13	.095	.0071	27.32	144.2
14	.083	.0054	20.85	110.1
15	.072	.0041	15.69	82.8
16	.065	.0033	12.79	67.5
17	.058	.0026	10.18	53.8
18	.049	.0019	7.27	38.4
19	.042	.0014	5.34	28.2
20	.035	.0010	3.71	19.6
21	.032	.0008	3.10	16.4
22	.028	.0006	2.37	12.5
23	.025	.0005	1.89	10.0
24	.022	.0004	1.46	7.8
25	.020	.0003	1.21	6.4
26	.018	.0002	.98	5.2
27	.016	.0002	.77	4.1
28	.014	.0001	.59	3.1
29	.013	.0001	.51	2.7
30	.012	.0001	.43	2.3

Table Showing the Relative Dimensions of Pure Copper Wire at 60° Fahrenheit.

Length and Resistance.		Resistance and Weight.		Nearest B. & S.
Ohms per 1000 ft.	Ohms per mile.	Ohms per lb.	Lbs. per Ohm.	
.050	.26	.00008	12457.5	0000
.057	.30	.00010	9566.7	000
.071	.38	.00016	6114.24	00
.089	.47	.00025	3918.56	0
.115	.60	.00042	2375.18	0–1
.128	.67	.00052	1907.59	1
.154	.81	.00076	1319.50	2
.182	.96	.00106	940.844	3–2
.213	1.13	.00145	686.911	3
.250	1.32	.00201	497.96	4
.319	1.68	.00325	307.822	5
.379	2.00	.00460	217.343	6
.471	2.49	.00711	140.689	7
.575	3.03	.01058	94.543	8
.717	3.78	.01645	60.804	8
.869	4.59	.02416	41.392	9–10
1.144	6.04	.04187	23.884	11–10
1.498	7.91	.07186	13.916	12
1.991	10.51	.12679	7.887	13
2.443	12.90	.19104	5.234	14
3.069	16.20	.30135	3.318	15
4.299	22.70	.59137	1.690	16
5.852	30.90	1.09596	.912	18
8.427	44.49	2.27254	.440	19
10.081	53.23	3.25299	.307	20
13.167	69.52	5.54848	.180	21
16.517	87.21	8.73038	.114	22
21.329	112.62	14.5579	.069	23
25.808	136.26	21.3142	.047	24
31.861	168.23	32.4863	.031	25
40.325	212.91	52.0367	.019	26
52.669	278.09	88.7724	.011	27
61.083	322.52	119.404	.008	28
71.688	378.51	164.462	.006	29

THE TELEPHONE.

The telephone is an electrical instrument for the transmission of speech by the electric current.

The abbreviation of the familiar name is "The 'Phone."

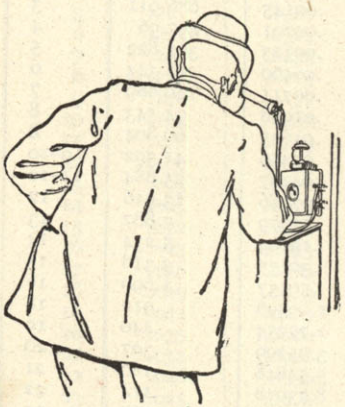


FIG. 258.

The thousand or more uses the telephone can be put to and its manifest convenience in rapidly transmitting messages make it the most remarkably time saver the world has ever known.

In the telephone the required improvements have been gradually developed, so that at the present time, instead of communicating telephonically over even short distances with great difficulty and uncertainty, it is now as possible and practicable to carry on conversation over a line 200, 500 or 1,000 miles long as to converse face to face.

THE TELEPHONE.

Figs. 258 and 259 exhibit the telephone as in practical use.

The main principle of the telephone is electro magnetism, as in the telegraph, but with many important differences.

When compared with telegraphic instruments, the telephone is found to be exceedingly sensitive. A sounder requires about the tenth of an ampere to work it properly, a relay, about the hundredth of an ampere; but a telephone will render speech audible with less than the millionth of an ampere, and is, therefore, more than ten thousand times more sensitive than a telegraphic relay.

FIG. 259.

In operation a line wire terminating in ground plates with a telephone in circuit at each end is the first condition. In the combination one instrument may represent a dynamo and the other a motor. The parts of the telephone which need principally to be named and described are:

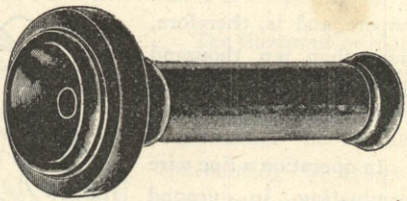
1. The Induction Coil.
2. The Vibrating Diaphragm.
3. The Transmitter.
4. The Receiver.
5. The Carbon Button, etc.

The Induction Coil (see Fig. 264), consists of a magnet with a coil of insulated wire surrounding it. In practice, the induction coil has a half inch core of soft iron wires on which are wound three layers of No. 16 wire (A. W. G.), and upon this is wound a secondary wire, which consists of No. 23 (A. W. G.), a sufficient quantity being used to make the resistance of the secondary about 17 ohms. The length of the coil between the flanges of the spool on which it is wound is 6 inches. Facing the pole of

FIG. 260.

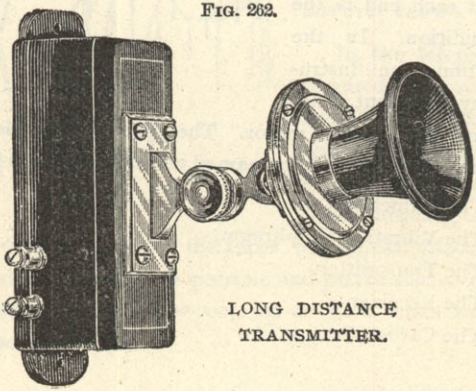
MOUTH PIECE.

FIG. 261.



TRANSMITTER AND RECEIVER.

FIG. 262.



LONG DISTANCE TRANSMITTER.

the magnet is the receiving diaphragm, which consists of a thin plate or disc of iron fixed at its edges and set in motion by the sound waves which strike it, due to the variations in the current passing over the line.

The Receiver.—See illustrations on page 468. The telephone applied to the ear is a receiver, while the one which is spoken into is the transmitter.

The Transmitter.—See illustration on page 468. Any instrument which produces signals to be transmitted through a line or circuit is a transmitter.

The Diaphragm.—This is a disk of iron thrown into motion by the sound waves or by electric impulses. Behind this diaphragm and very close to it is placed a carbon button. Between this carbon button and the diaphragm is a small piece of platinum which is placed so as to touch both the button and diaphragm very lightly.

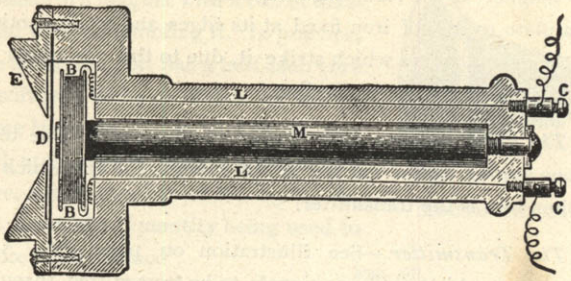
NOTE.—The average day's work of the New York telephone system is 150,000 calls. A peculiarity of the telephone traffic is that, although the service is permanent, the great use is crowded into a few hours of the day. Ninety per cent. of the calls are made between nine in the morning and five in the evening. The high-pressure time is between ten and noon, when calls pour in at the rate of over 19,000 an hour.

In the operation of the plant some 1,300 persons are employed. About half of these are engaged in handling the traffic, and the rest are divided between office construction and inspection departments.

A telephone operator in the Cortlandt Street exchange can find out in a second if one out of over 4,000 subscribers connected to that office is "busy," in about five seconds she can know if any one of the 15,000 subscribers in New York City is "busy," a few seconds more will enable her to get the same information regarding any one of 13,000 more subscribers in Brooklyn and New Jersey towns, and in a minute or two she can tell an inquirer if any particular subscriber in Boston, Buffalo, Philadelphia, Pittsburg, Washington, Chicago, or a hundred other places, is or is not using his telephone. And all without leaving her place—so long an arm does the telephone system give to a single young woman.

THE TELEPHONE.

FIG. 263.



THE BELL TELEPHONE.

The Bell Telephone.—In Fig. 263 is shown the construction of the Bell telephone in universal use as the receiver. M is a bar magnet in a case L, L. B B is a bobbin or coil of insulated wire surrounding one end of the magnet. D is the diaphragm. E is the mouth piece.

The terminals in the coil B B connect with the binding screws C C.

Practical Operation of the Telephone:

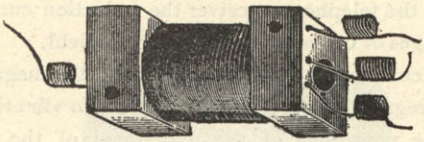
1. Atmospheric sound-waves strike the diaphragm of the telephone and cause it to vibrate.

2. The vibrating diaphragm produces a change in the magnetic field of the telephone.

3. The changes in the magnetic field induce currents in the wire coil of the telephone.

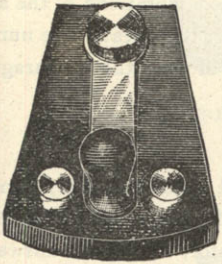
4. The induced currents are transmitted from the transmitter telephone through the line to the receiver telephone.

FIG. 264.



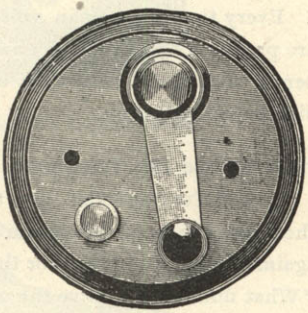
INDUCTION COIL.

FIG. 265.



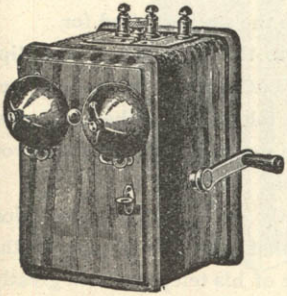
TWO POINT SWITCH.

FIG. 266.



SWITCH.

FIG. 267.



MAGNETO BELL.

FIG. 268.

TWO TWIST INSULATED WIRE.

THE TELEPHONE.

5. In the telephone receiver the induction currents produce changes of intensity in the magnetic field.

6. In consequence of these changes in the magnetic field, the diaphragm of the receiver is thrown into vibration.

7. The vibrations of the diaphragm of the telephone receiver give rise to air waves, which are propagated to the tympanum of the ear.

Every time the human voice is used vibrations of the air are produced and the louder and higher the greater the number of vibrations—with each change of tone the diaphragm vibrates in sympathy.

How to Use the Telephone.

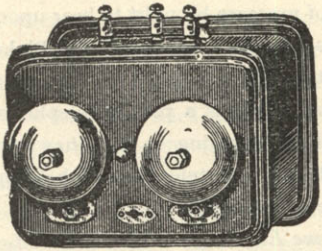
To call Central Office, give the bell crank one sharp turn; then take the hand telephone from the hook, place it firmly against the ear and listen for the operator, who should answer, "What number?" Give the operator the number of the subscriber desired, who will then repeat back your order, and may, to avoid errors and to expedite the service, ask for further information in relation to the station called for.

In talking, speak directly into the transmitter, with lips as close as possible to the mouth-piece. When you are through talking return the hand telephone to the hook, give the bell crank one sharp turn, to notify the operator that you have completed your conversation.

Speaking clearly and distinctly gives better transmission than shouting. It is obvious that the user is part of the "system" and by the proper use of his telephone can greatly promote the general efficiency of the service.

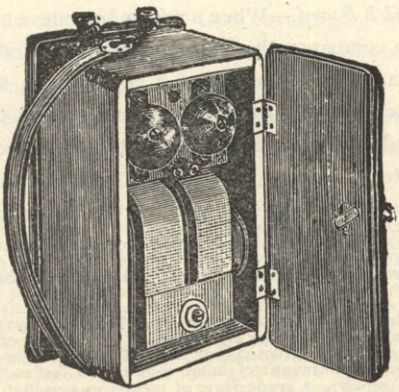
THE TELEPHONE.

FIG. 269.



MAGNETO TESTING INSTRUMENT.

FIG. 270.



MAGNETO TESTING INSTRUMENT (OPEN.)

THE TELEPHONE.

Carbon Telephone.—This is a telephone transmitter based on the use of carbon as a material whose resistance is varied by the degree of pressure brought to bear upon it. Many carbon telephones have been invented—the Blake transmitter is one of the most noted.

Bi-Telephone.—This is a pair of telephones carried at the end of a curved bar or spring so that they fit the head of the person using them; one telephone is held against each ear without the use of the hands.

The Telephone Exchange.—This is the office to which telephone wires lead in a general telephone system. The value of a 'phone to each subscriber depends upon the number of other subscribers on the line, or more correctly speaking, on the number with whom a subscriber can be placed in direct communication within any part of city or county or state.

The Switch Board.—When a person becomes a subscriber to a telephone company, the telephone placed in office or residence is connected by means of a copper wire to a certain point on the switch board in the exchange, and to this same switch board all other wires entering this same exchange are also connected. Then a cord or loop having terminal plugs enables the operator at the switch board to "connect in" any two subscribers. This action on the part of the operator virtually creates a private line each and every time a connection is made.

NOTE.—The modern telephone exchange is practically the creature of accident. For, in 1877, in New Haven, Conn., a number of private telephone lines were so constructed that they all passed through one office, thus minimizing the amount of labor required to test each new circuit and keep it in repair. A crude form of switch was used in making the tests, and, on one occasion, an employe all unconsciously so disarranged this switch that, in place of the two persons at the respective ends of a private line talking together, two private lines were connected in circuit and four points or stations provided with the means of communication.

THE TELEPHONE.

The subscriber, in ringing his bell, causes a current of electricity to pass through a small coil of wire with an interior core, which core, when electrified, attracts a small lever, and this lever, in moving, allows the above mentioned drop to fall. Consequently, when a person becomes impatient and rings the bell of his telephone long and hard, he does not startle the telephone office by the noise, as he might be led to suppose; the drop simply falls.

Under the streets of New York City there is a network of subways. The cables contain usually fifty-one pairs of wires, and are pulled through the three-inch subway iron pipe called a duct.

After each wire has been connected with the corresponding one in the other cable, hot paraffine is poured over the loose wires; a lead sleeve is slipped over the joint, each end of the sleeve being sealed with hot lead, thus making a water and air tight connection with the lead covering of each cable. Great care must be exercised to prevent the wires of the cable from becoming moist or damp, due to poorly connected joints, for there would then be electrical leakage, or the resistance of the wires would be reduced, as water saturated with impurities is a good conductor of electricity.

NOTE. The method of drawing a cable through a long stretch of subway between two manholes is quite ingenious. A man stands in the manhole with a bundle of short rods, about three feet in length, with brass ends so constructed that one will fit into another and stand a large amount of pushing or pulling without parting. A rod is inserted in a duct; another one is then clamped on and pushed forward, this process of joining being continued until the first rod appears at the next manhole. The last rod has a small rope fastened to it, the latter being in turn joined to a No. 6 wire, which is made fast to the end of the cable. A man in the second manhole disconnects the rods and draws the rope and wire through. The latter is made fast to a windlass, and by this means the lead cable, weighing about six pounds per foot, is slowly unreeled and drawn through the duct.

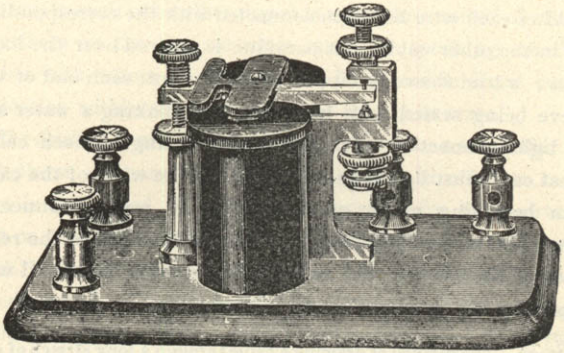
THE TELEGRAPH.

The telegraph consists in a combination of four things, namely:

A battery, which produces a current of electricity.

A line wire, which conducts that current from one point to another.

FIG. 271.



THE TRANSMITTING KEY.

A transmitting key.

An electro-magnetic apparatus, which gives out in sounds or sounding strokes all the signals which are made by pulsations of that current from a distant point.

THE TELEGRAPH.

Telegraph companies on their long lines use batteries of from twenty to a hundred cells each.

In telegraphy, it is found necessary to use non-conductors wherever the wire is fastened; for this purpose, glass is principally used for outside wires. The glass "insulator" is placed on a wooden pin or "bracket" which is fastened to the pole or building on which the wire is to be supported, after which the wire is strung and tied to the glass with a short piece of iron "tie wire." Inside of offices, hard and soft rubber tubes are used where the wires pass through the windows, and the copper conducting wires are usually covered with a coating of gutta-percha or wrapped with a continuous covering of cotton or silk. The latter is principally used as

---

NOTE.—"The public," says the *Electrician*, in a description of this apparatus, "considered the eletric telegraph merely as a pure novelty up to the day that it served to bring to justice a man who had committed a horrible crime. The telegraph was then recognized as a communicating agent of the highest value.

"The dispatches exchanged on that occasion are engraved upon brass plates that are borne by the very instruments that were used at the time. The inscription that the Paddington apparatus bears is as follows:

"On the first of January, 1845, the following telegram was received by this instrument at the Paddington station:

"'A murder has just been committed at Salt Hill, and the supposed murderer was seen purchasing a first class ticket for London by the train that left Slough at half past seven o'clock in the evening. He was in the garb of a Quaker, with a long brown coat that reached nearly to his feet. He is in the last compartment of the second first class coach.'

"On the first of January, 1845, the following answer was sent from Paddington:

"'The train has just arrived, and a person answering in all repects to the description given by telegraph came out of the compartment named. I pointed the individual out to Police Sergeant Williams. The man entered a New Road omnibus, and Sergeant Williams got in with him.'"

a covering for wires inside the finer instruments. For the handles or knobs to the various instruments hard rubber is generally used.

The operation of a telegraph is not, as many people suppose, a complicated or difficult matter to understand. The apparatus employed is quite simple, and easily understood.

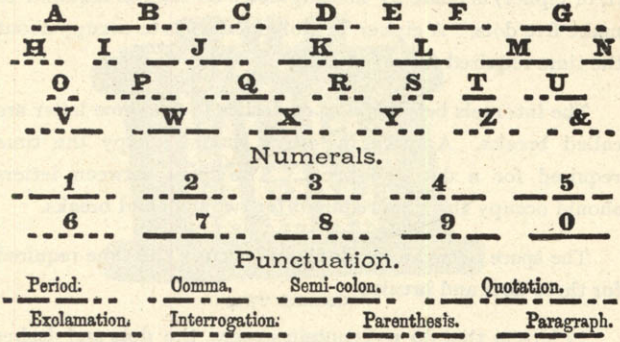
The battery is the first essential part of a telegraphic apparatus, as it is by the chemical action in the battery that the electric current is first generated. In practical telegraphy this current is made to traverse long or short distances through the conducting medium of metallic wires, and by means of the proper instruments, made to give out tangible results.

The basis of the entire telegraphic mechanism is the Electro-magnet and the transmitting "Key," (see Fig. 271.) The Electro-magnet is constructed as follows: two bars of soft iron, having round heads of hard rubber, thus making spools of each, are joined together by means of a short flat bar of iron similarly soft. The round bars in the spool of the magnet are called cores, the flat connecting bar at the back is called the "back bar" or "heel piece." The movable flat piece of iron in front which is to be attracted by magnetism to the cores, or withdrawn by the spring when no magnetism excites the cores, is called the armature.

A silk or cotton-covered wire is wound in continuous turns about the cores, until the diameter of about an inch and a half is attained, and each core or spool of the magnet contains

a great number of turns of the wire around it. Now, if a current of electricity be sent through this wire, it will, by its passing through the numerous turns, cause the iron cores within to become magnetic and to possess the power of attracting with considerable force any piece of iron brought near to their ends.

THE MORSE TELEGRAPH ALPHABET.


A B C D E F G
H I J K L M N
O P Q R S T U
V W X Y Z &
Numerals.
1 2 3 4 5
6 7 8 9 0
Punctuation.
Period. Comma. Semi-colon. Quotation.
Exclamation. Interrogation. Parenthesis. Paragraph.

The Morse alphabet consists of what are called dots, dashes and spaces. Combinations of these make intelligible signals. Many of the characters will be found to be the reverse of others: such as A is the reverse of N; B of V; D of U; C of R; Q of X; Z of &; so if the formation of one of these letters be obtained, its reverse is easily mastered. C, E, H, I, O, P, R, S, Z, Y, are merely represented by dots and spaces, and, if due regard be given to them, they will be found very easy to commit to memory,

THE TELEGRAPH.

The first step is to memorize the alphabet, so that each character can be called to mind at will ; thus, A, dot and dash ; B, dash and three dots ; C, two dots, space, dot, etc. The period is the only punctuation mark in frequent use.

A dot (E) is made by a single instantaneons, downward stroke of the key. A short dash (T) is made by holding the key down as long as it takes to make three dots. A long dash (L, or cipher) is made by holding down as long as required to make five dots. A cipher is prolonged so as to occupy about the time required for seven dots.

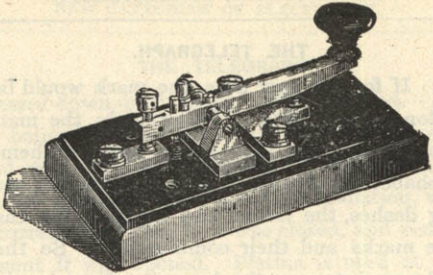
The intervals between dots or dashes in the same letter are called breaks. A space in letters should occupy the time required for a dot and break. The space between letters should occupy the time required for two dots and breaks.

The space between words should occupy the time required for three dots and breaks.

In letters that do not contain spaces, the dots and dashes should follow each other as closely as possible.

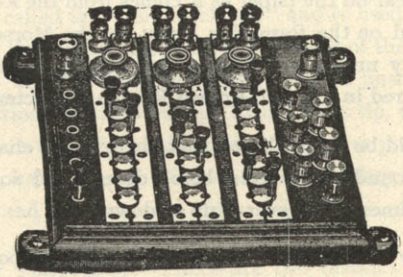
The armature of the magnet is attached to a lever, and this lever, which swings on a pivot in the middle, is provided at the end with a pointed pin or screw, which is caused to press upwards against a strip of paper whenever the magnet attracts, and to return to its former position when the attraction ceases. Meanwhile the paper is kept moving steadily forward, so that if the lever-pin is pressed against the paper, for only an instant of time, a short mark or *dot* appears pressed or embossed into

FIG. 272.



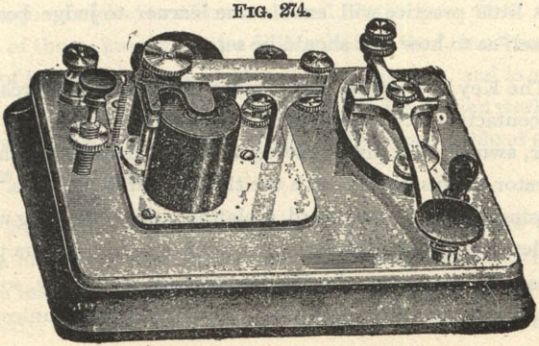
THE MORSE KEY.

FIG. 273.



KEY BOARD.

FIG. 274.



TELEGRAPH KEY AND RELAY.

the paper. If for a longer time, the mark would be proportionately longer, or a *dash*. If alternately, the marks would come consecutively, and have *spaces* between them. As the Morse Alphabet consists entirely of dots, dashes, spaces, and extra long dashes, the letters and numerals are easily made with these marks and their combinations. So that as the hand of the operator, on the key at a distant point, makes short or long strokes, dots or dashes, or spaces, these same marks appear on the paper as it comes from the Register, and being based on the formation given by the Morse Alphabet, are as easily understood by the receiving operator as though they appeared in the well-known Roman characters.

It should be remembered that there is no change in the tone of a sounder, the letter being determined solely by the "time or times" the lever is up or down.

The key is provided with screws for the purpose of regulating its play to suit the hand of the operator.

A little practice will enable the learner to judge best for himself as to how this should be set.

The Key is a simple contrivance for making or breaking the contacts which control the passage of the current—a steel lever, swung on a pivot, having a rubber handle, which the operator grasps lightly with the thumb and forefingers. On pressing the lever downward, a platina point projecting under the lever is brought into contact with another platina point set into an insulation of rubber in the base of the key, so that there can be no electrical connection between them unless the

key is pressed down, or "closed," as it is termed. A conducting wire being separated at any point, and one of its ends connected with the lever or base of the key, and the other end with the metal set into the rubber insulation, would convey the current while the key was closed, and cease to do so the moment it was opened. Platina is used at the points where the electrical contacts are made and broken, because it does not readily fuse or tarnish. An extra lever at the side of the key is called the "circuit-closer," and is used as a means of keeping the circuit closed when the hand of the operator is not on the key. When the circuit-closer is pushed into its closed position, it makes contact with a brass lip, which latter is fastened to the rubber along with the lower platina point. This, then, has the same effect as though the key was pressed downward and contact made at the points.

Duplex Telegraphy.—There are two distinct methods of arranging telegraphic apparatus so as to transmit two messages through one wire, one from each end, at the same time. The first of these, known as the differential method, involves the use of instruments wound with differential coils, and is applicable to special cases. The second method of duplex working, known as the Wheatstone's Bridge Method, is capable of much more general application.

The Relay.—In working over long lines, or where there are a number of instruments on one circuit, the currents are often not strong enough to work the recording instrument directly. In such a case there is interposed a relay or repeater.

THE TELEGRAPH.

This instrument consists of an electromagnet round which the line current flows, and whose delicately poised armature, when attracted, makes contact for a local circuit in which a local battery and the receiving Morse instrument are included. The principle of the relay is, then, that a current too weak to do the work itself may set a strong local current to do its work for it.

Another term for this instrument is "the relay magnet,"

The use of the relay is especially required in the Morse system of telegraphy in order to cause the sounder to be more distinctly heard; the use of the relay permit much smaller currents to be used than could otherwise be done.

Faults in Telegraph Lines.—Faults may occur in telegraph lines from several causes: either from the breakage of the wires or conductors, or from the breakage of the insulators, thereby short-circuiting the current through the earth before it reaches the distant station, or, as in overhead wires, by two conducting wires touching one another. Various modes for testing the existence and position of faults are known to telegraph engineers; they depend upon accurate measurements of resistance or of capacity. Thus, if a telegraph cable part in mid-ocean it is possible to calculate the distance from the shore end to the broken end by comparing the resistance that the cable is known to offer per mile with the resistance offered by the length up to the fault, and dividing the latter by the former.

THE TELEGRAPH.

Submarine Telegraphs. Telegraphic communication between two countries separated by a strait or ocean is carried on through cables, sunk to the bottom of the sea, which carry conducting wires carefully protected by an outer sheath of insolating and protecting material. The conductor is usually of purest copper wire, weighing from 70 to 400 lbs. per nautical mile, made in a sevenfold strand to lesson risk of breaking. In the Atlantic cable, which is of the usual type of cable for long lines, the core is protected first by a stout layer of gutta-percha, then by woven coating of jute, and outside all an external sheath made of ten iron wires, each covered with hemp. The shore ends are even more strongly protected by external wires. (See Fig. 42, page 97.)

Culley states that when a current is sent through an Atlantic cable from Ireland to Newfoundland no effect is produced on the most delicate instrument at the receiving end for two-tenths of a second, and that it requires three seconds for the current to gain its full strength, rising in an electric wave which travels forward through the cable. The strength of the current falls gradually also when the circuit is broken.

ELECTRIC BELLS.

The electric bell is a bell rung by electricity.

Generally it is worked by a current exciting an electro-magnet attracting or releasing an armature which is attached

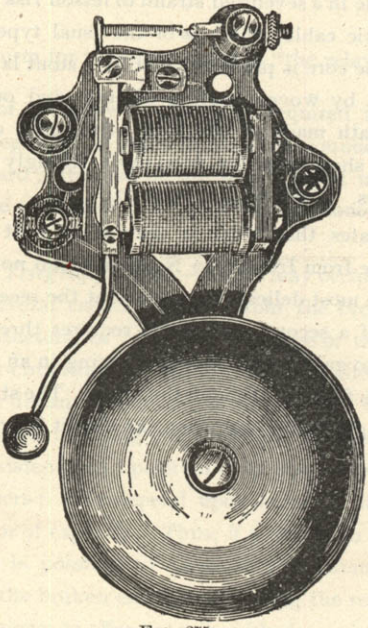


FIG. 275.

to the vibrating or pivoted tongue of the bell. This is done alternately so that the tongue beats against the bell.

ELECTRIC BELLS.

The arrangements of the instrument are shown in Fig 276, in which E is the electro-magnet and H the hammer. A battery consisting of one or two Leclanché cells placed at some convenient point of the circuit, provides a current when required. By touching the "push" P, the circuit is completed, and a current flows along the line and round the coils of the electro-magnet, which forthwith attracts a small piece of soft iron attached to the lever, which terminates in the hammer H. The lever is itself included in the circuit, the current entering it above and quitting it at C by a contact-breaker, consisting of a spring tipped with platinum resting against the platinum tip of a screw, from which a return wire passes back to the zinc pole of the battery. As soon as the lever is attracted forward the circuit is broken at C by the spring moving away from contact with the screw; hence the current stops, and the electro-magnet ceases to attract the armature. The lever and hammer therefore fall back again establishing contact at C, whereupon the hammer is once more attracted forward, and so on. The push P is shown in section on the right of Fig. 277. It usually consists of a cylindrical knob of ivory or porcelain capable of moving loosely through a hole in a circular support of porcelain or wood, and which, when pressed, forces a platinum-tipped spring against a metal pin, and so makes electrical contact between the two parts of the interrupted circuit.

The bell may be worked by a distant switch or press button ringing once for each movement of the distant switch or it may be of the—

ELECTRIC BELLS.

Vibrating Bell Type.—When the current is turned on in this system it attracts the armature. As this moves towards the poles of the magnet it breaks the circuit by drawing the "contact spring" away from the "contact point."

This opens the circuit as before explained and causes the continual ringing.

FIG. 276.

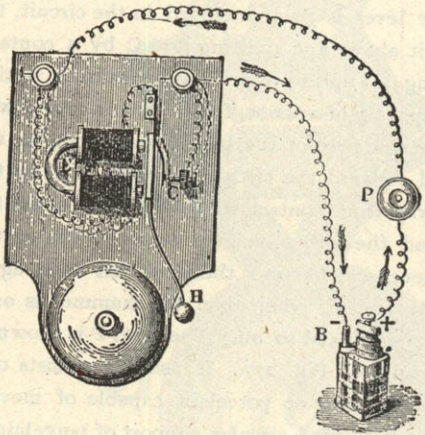
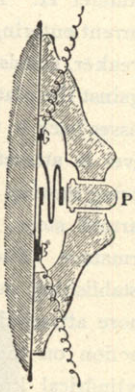


FIG. 277.



DEFECTS OF ELECTRIC BELL.

The possible defects of electric bells may be classed under four heads, viz. : 1st, bad contacts ; 2d, bad adjustment of the parts ; 3rd, defective insulation ; 4th, warpage or shrinkage of base. Many operators are content with simply turning the

terminal wires round the base of the binding-screws. Unless the binding-screws are firmly held down on to the wires by means of a back nut a great loss is sure to occur at these points, as the wires may have been put on with sweaty hands, when a film of oxide soon forms, which greatly lowers the conductivity of the junction. Again, at the junction points of the wires with the contact angle brass and contact pillar, some workmen solder the junctions, using "killed spirits" as a flux.

If solder be used at any parts, let *resin* be used as a flux. Even if any excess of resin remain on the work, it does no harm and does not destroy the insulation of any of the other portions. Another point where bad contact may arise is at the plantinum contacts. Platinum is a metal which does not rust easily, even under the influence of the electric spark given at the point of contact. Therefore it is preferred to every other metal (except, perhaps, iridium) for contact breakers.

As to bad adjustment; it is evident that the magnets and the armature must stand at a certain distance apart to give the best effects with a given battery power. The distance varies from $\frac{1}{24}$ in. in the very smallest, to $\frac{1}{8}$ in. in large bells. Sometimes the armature adheres to the poles of the electro-magnet; this is due to *residual magnetism*, and points to hard or unannealed iron in the cores or armature. As a make-shift, this defect may be partially remedied by passing a thin piece of paper over that surface of the armature which faces the poles of the electro-magnets.

FIG. 278.

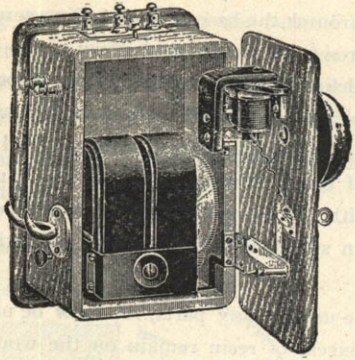


FIG. 279.

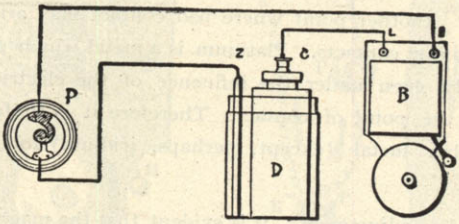
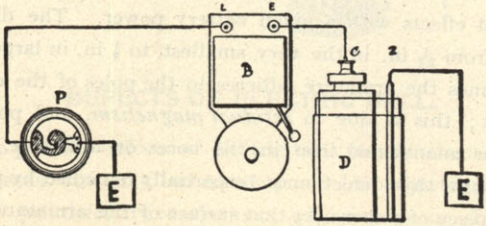


FIG. 280.



MAGNETO BELL.

ELECTRIC BELLS.

Another bad adjustment is when the platinum screw does not touch fairly on the centre of the platinum speck, but touches the spring or the solder. Rust is then sure to form, which destroys the goodness of the contact. To adjust the contact spring at the right distance from the platinum screw, hold the hammer against the bell or gong. The armature should now *just not touch* the poles of the electro-magnet. Now screw up the platinum screw until it *clears* the contact spring by about the thickness of a sheet of brown paper (say $\frac{1}{10}$ of an inch). Let the hammer go, and notice whether the contact spring makes good contact with the platinum screw. When this has been satisfactorily adjusted the back-nut or set screw may be tightened to insure that the vibration of the hammer shall not alter the adjustment.

The other points where the insulation may be defective are between the binding screws and the base, if this be all of metal; or between the contact spring block and the base, and the contact pillar. It is also probable (if the connecting wires have not been covered with india rubber tubing, as recommended) that leakage may be taking place between these wires and some portion of the metal work of the base or frame. This must be carefully examined.

Warpage or shrinkage of the base—can only occur in badly-made bells, in which the entire base is of wood. A cursory examination will show whether the board is warped or swollen, or whether it has shrunk. Warping or swelling will throw the electro-magnet too far from the armature, or "set" the pillar out of place; shrinkage, on the contrary, will

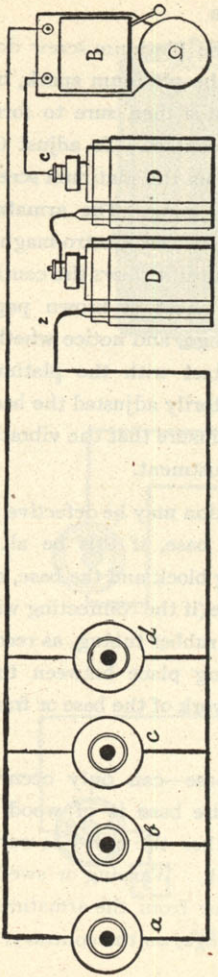


FIG. 281.

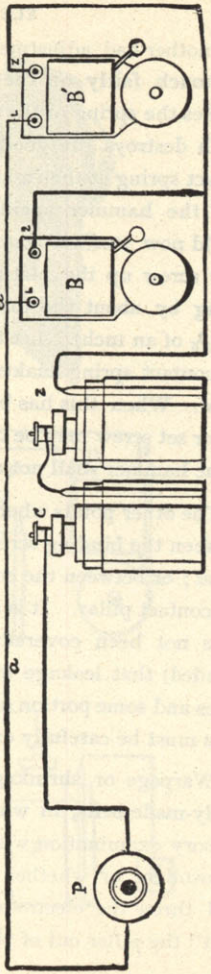


FIG. 282.

bring the parts too close together and jamb the magnets, the armature, and the contact pillar into an unworkable position.

No bell that is set to do real work should be fitted up without a cover or case. The dust which is sure to accumulate, not to speak of damp and fumes, etc., will certainly militate against good contacts and good action if this important point be neglected.

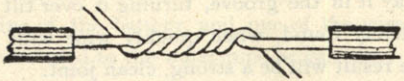


FIG. 283.

—JOINING TWO WIRES.

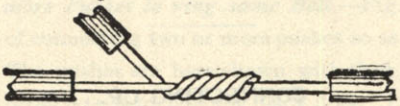


FIG. 284.

JOINING-ON A BRANCH WIRE.

To make a good joint, the following method of procedure should be adopted :—Strip the ends of the wires to be joined of their insulation for a length of about 1½ inches, and scrape clean with a knife or brighten with emery paper. Then (taking one wire in each hand) twist the wires together as shown in Figs. 283 and 284 (Fig. 284 is a branch wire), and tighten up with the plier. Now get ready the articles required for soldering, which should consist of the following :—A small copper bit, filed wedge shape with an ⅛-inch groove cut across one face ; a small spirit lamp for heating the bit, a stick of solder, and lastly, a piece of composite candle or

rosin. The best "blow-pipe" solder should be used, the quality of which may be tested by holding it up to the ear and bending it, when, if it is good, a peculiar crackling noise will be heard, which is known as the "cry of the tin." To solder the joint, heat the bit, previously tinned, in a spirit lamp or fire, and wipe with a piece of clean rag, and then, holding it with the grooved side upwards, fill the groove with solder. Now rub some composite candle or powdered rosin on the joint, and lay it in the groove, turning it over till the solder runs completely round, when quickly wipe with a piece of rag, and the result will be a strong, clean joint.

CONNECTING UP.

The following diagrams, 279 to 282, show several ways of connecting up bells, indicators, etc., and though the methods most usually required are shown, nearly every instance may require some little special modification.

Simple Bell Circuit.—Fig. 279 shows a simple circuit, consisting of push, battery, and bell. The cover of the push P has been removed, showing the connections to the contact springs, one of which, for the purpose of distinction, is shown darker than the other. The bell B (shown in detail in Fig. 275) has its cover on; thus none of the movement is visible. Z and C are the respective poles of the battery D. On the two springs of the push being pressed together the

current flows from the positive pole C of the battery to the terminal L, through the bell to the terminal E, and thence by the wire and push-springs to the negative pole Z. Both in this and the following figures the Z or return wire is shown thicker, in order to make the diagrams clearer.

Simple Bell Circuit with "Earth."—Fig. 280 is a simple bell circuit with "earth" connections, the circuit being completed between the two plates E E by the earth; the wire from the zinc of the battery, and one of the wires from the push being fastened to the water-pipe or gas-pipe.

Two or more Pushes to ring same Bell.—Fig. 281 shows the method of connecting two or more pushes so as to ring the same bell. The pushes are here shown with their covers on, the buttons being represented by the black dots. Pressing the button of either of the pushes *a*, *b*, *c*, *d*, completes the circuit, causing the bell B to ring.

Two Bells to ring simultaneously from one Push.—Fig. 282 shows an arrangement by means of which two bells can be rung simultaneously from one push, the bells being some distance apart, as in separate rooms. On the button of the push P being pressed in, the current flows from the positive pole C of the battery through the push, and along the wire *a* to *d*, where it devides, half (if the bells are of equal resistance) passing through the bell B, and half through the bell B′. When bells are arranged parallel like this, care should be taken to insure the resistance of the coils of each bell being as near

alike as possible, or else to put the bell with the lowest resistance the furthest from the battery, so that the resistance of the line compensates for its lower resistance. If there are many bells, care must also be taken to provide sufficient battery power, the largest sized cells being used. The practice of splitting up a battery of smaller cells into two halves, and connecting the halves in parallel, is not advocated, unless absolutely necessary, it being far preferable to employ larger sized cells.

Push Buttons.—These are switches (see Figs. 285 and 286) for closing a circuit by means of pressure applied to a button. The button is applied to a spring so that when pushed in and released it springs back; thus the circuit is closed only as long as the button is pressed.

Pulls.—These are switches for closing a circuit when pulled.

Magneto Bell and Generator.—Fig. 278 shows a small magneto bell and generator, there being also a switch hook at the bottom, since the generator is mainly used for telephony, which is the chief field of the magneto bell. The generator is, it will be seen, fixed in the body of the case, while the bell is on the lid. The hammer-head, projecting through a hole, works between the two gongs.

The apparatus required for signalling by the method mentioned above consists of two parts—the generator and the bell. The principle on which the generator acts is the same

as that on which is based the action of all dynamos, and, in fact, the generator finds in the dynamo almost its exact counterparts.

The Electric Buzzer is a very useful instrument for use in places where the ringing of a bell would be an annoyance. It operates on the same principle as the electric bell and can be adjusted to emit a musical and pleasing hum instead of the ordinary ringing.

The direction of the current cuts no figure in this class of work; connect the opposite ends of the circuit to the opposite ends of the circuit to the opposite poles of the battery and the circuit is complete.

Wiring plans and specifications should be worked out by electrical engineers rather than architects or builders, as the problems of wastage of current and the danger to life and property are extremely difficult to work out under all the varying conditions.

"Diagrams" should be made showing in detail the connections actually required, and these should be provided at an early stage of any installation.

ELECTRIC BELLS.

Explanation of Technical Terms used in Electric-bell Work.

Battery.—The combination of cells which furnish the current of electricity for working the bells, indicators, &c.

Cell.—Each outer jar of the battery, with its two elements and exciting fluids constitutes a cell.

FIG. 235.

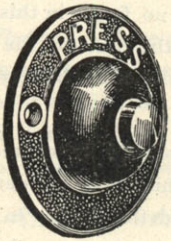


FIG. 236.

Circuit.—The wires, bells, indicators, batteries, &c., forming the path for the electricity.

Deflection.—The angle or number of degrees through which the needle of the detector moves during the passage of a current round the coils.

Earth return.—The use of the earth as part of the circuit.

Earth wire.—The wire from the bell, battery, &c., leading to the water or gas pipes.

ELECTRIC BELLS.

Fault.—Any break or interruption of the circuit by which some of the operations are interfered with.

Line.—The wire joining one station with another.

Line Battery.—The battery which is used to send the currents to line.

Local battery.—The battery placed near the bell or apparatus required to be worked which continues the ringing of the bell after it has been once started by the current from the line battery.

Local circuit.—The circuit through which the current of the local battery flows.

Metallic circuit.—The use of another wire for return instead of earth.

To connect up.—To join the bells, indicators and other apparatus included in the circuit.

To disconnect.—To remove the ends of the wires from the terminals of the instrument, thus cutting it out of the circuit.

To make "earth."—To connect the wire to earth.

A short-circuit.—A fault caused by two wires coming together so as to form a shorter path for the current, diverting the whole or greater part of it from its proper course.

To short-circuit a cell.—To join the terminals with a piece of wire.

To short-circuit an instrument.—To join the terminals of the bell, &c., with a piece of wire.

ELECTRIC PUMPS

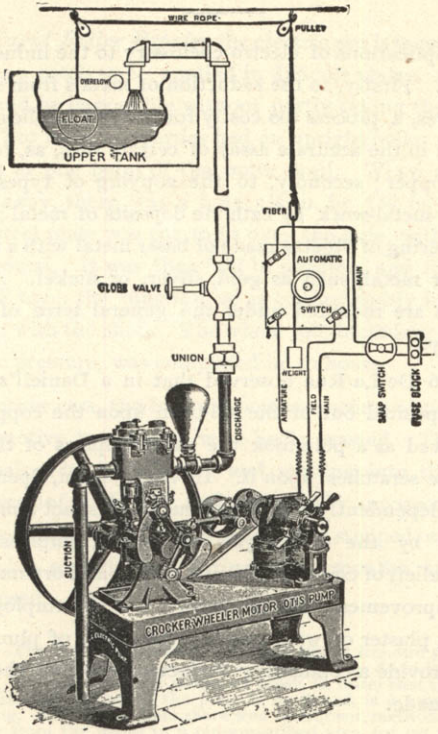
Pumps suitable for all services are built to be driven by electric motors, and special designs have been made to cover the requirements of hydraulic elevator service, mine service, water works supply, irrigation purposes, fire protection, or in short any service where electric motive power can be used to advantage.

The great variety in style and size of these pumps now in successful use assures the extension and enlargement of the application of electric motors to all kinds of pumping machinery.

Fig. 287 shows a motor attached to a pump with governing arrangement which is very simple in construction. The pulley of the switch is connected by a chain to a float resting upon the water in the tank, so that when the water falls the wheel is revolved until the starting point is reached, when it causes the switch arm to pass slowly over the contacts until the full current is cut in, and the motor runs at full speed. As the water rises, through the action of the pump, the pulley is turned in the opposite direction, finally making a quick break, shutting off the current and stopping the motor. This switch is positive in action, and cannot fail to work at all times and under all circumstances. It prevents the tank from overflowing or becoming empty through neglect of the attendant.

ELECTRIC PUMPS

FIG. 287.



ELECTRIC PUMP AND AUTOMATIC TANK SWITCH.

ELECTROMETALLURGY.

The applications of electro-chemistry to the industries are three-fold. Firstly, to the reduction of metals from solutions of their ores, a process too costly for general application, but one useful in the accurate assay of certain ores, as, for example, of copper; secondly, to the copying of types, plaster casts, and metal-work by cathode deposits of metal; thirdly, to the covering of objects made of baser metal with a thin film of another metal, such as gold, silver, or nickel. All these operations are included under the general term of electro-metallurgy.

In 1836 De La Rue observed that in a Daniell's cell the copper deposited out of the solution upon the copper plate which served as a pole took the exact impress of the plate, even to the scratches upon it. In 1839, Jacobi, Spencer, and Jordan independently developed out of this fact a method of obtaining, by the electrolysis of copper, impressions (in reversed relief) of coins, stereotype plates, and ornaments. A further improvement, due to Murray, was the employment of moulds of plaster or wax, coated with a film of plumbago in order to provide a conducting surface upon which the deposit could be made.

Electro Plating or Electro Deposition.—The full details of the many processes for electro plating cannot be given on account of their length; the general principle includes a bat-

tery or source of electric current (say a dynamo of suitable size, etc., as shown and explained in connection with illustration 288.)

For Rapid Boiler Repairs the electric arc is most efficient. It enables a patch to be applied in difficult places, where riveting would be impossible without partly taking the boiler to pieces. For instance, parties had an upright boiler wasted by corrosion at one point of the outer shell. When the defect was cut away, there was a hole 5½ in. by 3½ in. A piece of mild steel plate was cut to fit over the hole, with 1 1-2 in. lap all around. It was then laid in position, and the electric arc struck upon the junction, so as to thoroughly incorporate the patch with the shell. The whole job, including testing by hydraulic pressure, was completed in 10 hours.

In another case, the internal bottom corners of the fire-box of a locomotive type boiler were badly wasted. The defects were repaired by building on and melting into the recesses small pieces of mild steel, and thoroughly incorporating the new pieces with the old. The leaks were stopped, and no further trouble experienced during eight months which have since elapsed.

NOTE.—The extreme hardness of armor plates has one great disadvantage, it is impossible to cut or drill them, and to do so is often very necessary. To exactly locate proposed holes, in order that they may be drilled before the surface of the plate is hardened, is a very expensive undertaking. For a long time there was no known method of drawing the temper from the metal in a circumscribed area, for no matter how heat was applied, the large mass of metal produced such rapid cooling as to retemper the spot. By means of electricity, however, the problem has been solved, and a small section of a plate, where it is desired to drill a hole, may be heated to 1,000 degrees and very slowly cooled, thus drawing the temper satisfactorily.

ELECTROMETALLURGY.

FIG. 288.

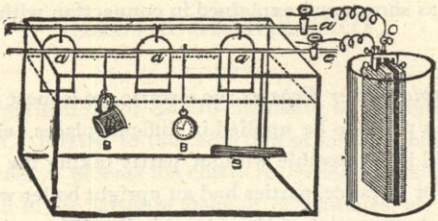


Fig. 288 represents the operation of plating, the position of the anode and cathode, the battery and the bath. The battery has its centre or positive plate connected to a rod extending across the trough, to which are suspended the anodes, *a*, *a*, *a*, of gold, silver or copper, or whatever other metal from which to obtain a deposit. The other plates of the battery, or the negative elements, are connected with the remaining rod across the trough, to which are suspended the articles to be plated, *b*, *b*, *b*.

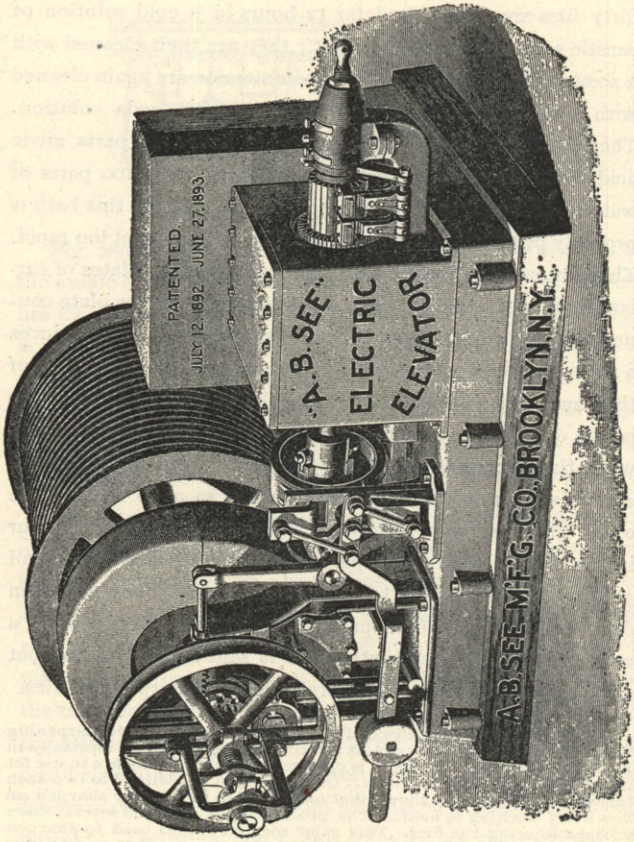
Electricity in Drilling.—The electric current is now used extensively to aid in drilling hardened steel. By this means the steel is softened in a very limited space by sending the current, of sufficient strength, through the metal at the required point. The terminal of one of the conductors is placed at the point where it is required to drill the hole and the terminal of the other conductor on the opposite side where the drill is intended to pass through. The application of current between these points will soften the metal in a direct line between the terminals without affecting a greater area than is desired. The metal being thus softened no great difficulty is experienced in drilling it afterward (see Note, page 503.)

ELECTROMETALLURGY.

Sharpening Files by Electrical Process.—The dull and dirty files are first placed for 12 hours in a cold solution of caustic soda of 15 to 20 per cent.; they are then cleaned with a scratch brush and after another immersion are again cleaned with a scratch brush and a 5 to 6 per cent. soda solution. They are then placed in the following bath: six parts nitric acid of 40 degrees; 3 parts of sulphuric acid; 100 parts of water. It is said to be very important to see that this bath is properly proportioned in order that the action is not too rapid. They are inserted in this bath, and connected to plates of carbon immersed close to them, by means of a copper plate connecting all the carbons and the files at the top. This produces a short-circuited battery which generates gas on the surface of the files. The gas formed creates bubbles which adhere to the points of the files, and protect them from being eaten away, while the rest of the file is being etched. They are taken out every five minutes and washed in water so as to remove the oxide which collects. They are then placed for half an hour in lime water made of one part by weight of slacked lime and 50 parts water; this is to remove the acid. They are then dried in sawdust and to prevent rusting are rubbed with a mixture of oil and turpentine. It is said that it requires but 20 to 30 minutes in the electrolytic bath to sharpen the files.

NOTE.—The "Elek. Zeitschrift" states that the method of sharpening files, described some years ago, is meeting with great favor, especially in England and France, where it is used very largely. Baths are in use for treating 300 to 400 files at a time. One workman can attend to two such baths. Experience has shown that one man can in this way sharpen 400 files a day working 10 hours. The process can be repeated several times without injuring the files. This same method is also used to sharpen knives used in beet sugar factories. For this purpose it is said to give very good results and does not require any skilled labor, while at the same time it represents a considerable saving in the cost of sharpening knives.

FIG. 289.



ELECTRIC ELEVATOR.

THE ELECTRIC ELEVATOR.

The electric elevator—or as it is described in England, the Electric Lift—is a combination of the regular elevator with the electric motor; *i. e.*, the power applied to raise and lower, is the electric current, as against water pressure or steam pressure.

The adaptability of electricity to all service where power is required was never so apparent as in its application to passenger elevators; the success of the electric hoist seems destined to develop a field the extent of which has not yet been calculated.

The essential features of the electric elevator are: (1) high speed, (2) absolute safety, (3) completely under control of operator, (4) applicable to the current to be supplied by the lighting mains, (5) low cost of operation and maintenance.

In the hydraulic pumping system as well as in the hydraulic street pressure system, it is noteworthy that just as much water is required to carry up the empty car as to carry up a full load, and—

If a steam pump is used it is necessary to keep the fire burning under the boiler and to keep the steam up all the time, although the pump in most cases runs only a small portion of the time, so that the consumption of coal is many times larger in proportion to the power used than in ordinary steam engines of equal power, but—

THE ELECTRIC ELEVATOR.

If electricity is used in connection with a proper motor, the consumption of current stops when the work stops, which insures great economy of operation whether the current supply is obtained from a central station or from owner's dynamos.

The advantages of the device as summarized are as follows:

Advantages of the Electric Elevator.

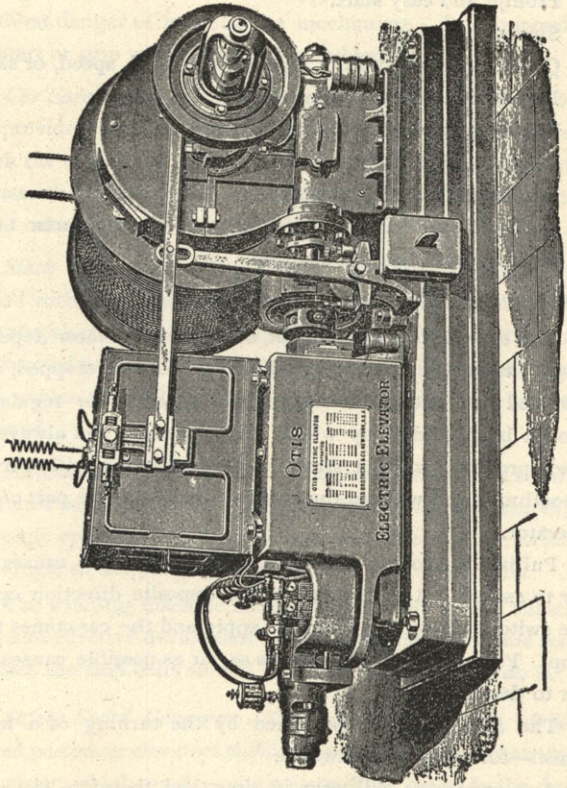
1. *As compared with hydraulic elevators.*

No frozen or burst water pipes.
No flooded cellars.
No piston to pack and grease.
No leaking valves or cylinders.
No air to cause runaways.
No excessive weight to bring car down.
No heavy or unsightly tanks on roof or pressure tanks occupying valuable space.
No creeping of car away from landing, if left for a few minutes.
No water pipes to fill up or corrode, thereby reducing power and speed.

As compared with steam elevators.

No odors or heat.
No ashes, dust, or dirt.
No boiler insurance.
No costly space occupied.
No vibration of building or disagreeable noises.
No consumption of coal while elevator is at rest.
No waiting to get up steam.

FIG. 290.



ELECTRIC ELEVATOR.

THE ELECTRIC ELEVATOR.

3. *General advantages.*

Prompt and easy start.
Smooth running.
Quick and smooth stop, regardless of load, speed, or skill.
Requires minimum attention.
Speed practically uniform under all loads.
Large margin of power.
Minimum operating expense.
Extreme simplicity, few moving and wearing parts.
Most approved safety devices.

"Points" relating to the Electric Elevator:

The satisfactory working of an electric elevator depends largely upon the devices by which it is started, stopped, and reversed; an automatic switch and rheostat (or regulator) should be provided, by which these changes can always be made properly without strain on the apparatus, with perfect smoothness and without the exercise of skill on the part of the operator.

Pulling the rope downwards as far as possible causes the car to ascend. A slight pull in the opposite direction opens the switch, allows the brake to apply and the car comes to a stop. Pulling the rope upwards as far as possible causes the car to descend.

The same effect is produced by the turning of a hand wheel—forwards or backwards.

Any apparatus will wear in time, and therefore elevators should be equipped with the most reliable and improved forms of safety appliances.

THE ELECTRIC ELEVATOR.

The advantages of the automatic method of control can hardly be overstated; with it any person can run the elevator without danger of injuring the mechanism. It is impossible to start or stop with disagreeable suddenness.

Car Safeties.—Each bottom guide shoe of the cage should be provided with a steel safety dog with rods connecting them with the cables, by means of levers in the cross head, so that in case the lifting cables break or slacken, the dogs will throw in at once and lock the car to the guides.

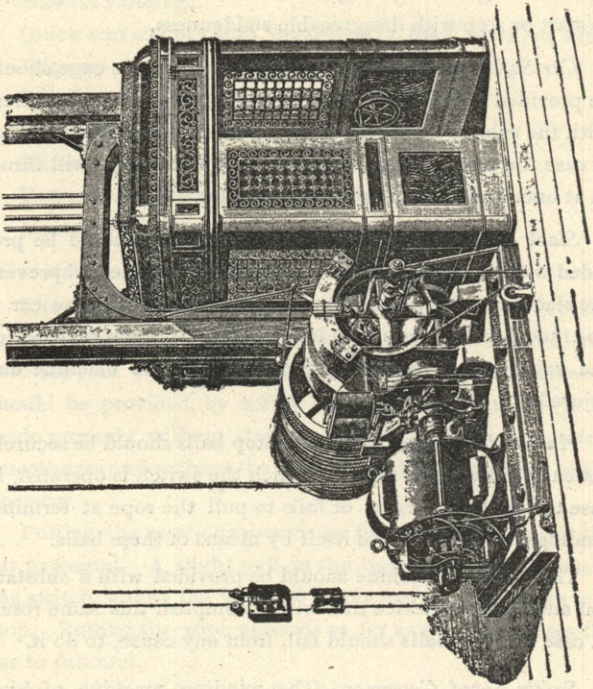
Slack Cable Stop.—The winding machine should be provided with an effective device to stop the machine and prevent the slacking of the cables upon the drum in case the car is obstructed in any manner in its descent. Without such device the cables might become entangled with the machine and injured.

Automatic Terminal Stops.—Stop balls should be securely fastened to the hand rope by which the switch is operated, in case the operator forgets or fails to pull the rope at terminal landings, so the car stops itself by means of these balls.

The winding machine should be provided with a substantial and effective device that will accomplish this same result in case the stop balls should fail, from any cause, to do it.

Safety Speed Governor.—The winding machine of high speed passenger elevators should be provided with a centrifugal governor, which applies a heavy auxiliary brake to the drum, in case of excessive speed due to any cause, bringing the whole apparatus to a stop.

FIG. 291.



ELECTRIC ELEVATOR FOR PASSENGERS.

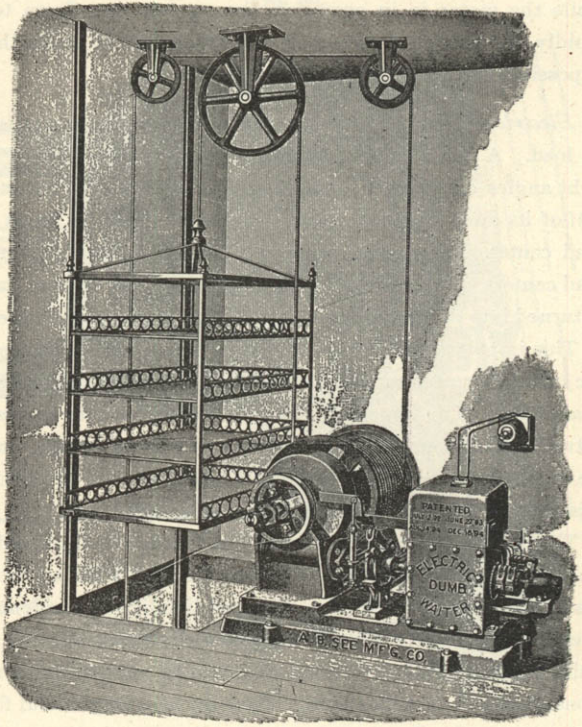
THE ELECTRIC ELEVATOR.

Safety Switch.—With some elevators if the electric current is interrupted by breaking of wires or by any other means while the motor is in operation, the car will run down too rapidly for safety; a switch so constructed as to make this impossible should be provided.

Electric Hoist.—A hoist does its heaviest work in starting its load. A steam hoist having two engines with cranks at right angles can only be depended upon at this time for one-half of its rated capacity, as one of the engines may be on a dead center. An electric motor, on the other hand, has no dead centers, and a heavy current in excess of the normal, can be turned into the armature for a few moments without danger. This important advantage is of great value, and gives electric hoists a greater capacity, other things being equal, than a steam hoist. The simplicity, too, is very apparent; instead of two link motions, we have a simple reversing switch, and the only parts subject to wear in the motor are the two bearings and the commutator. (See Fig. 108, page 235.)

The power is transmitted to the hoist through an intermediate gear and pinion, which is nicely covered with an iron guard, protecting it from dust, dirt, and liability of accidents. They are particularly convenient where an electric current is easily supplied, and very often they can be run much more economically than with steam. They are also very useful for contractors and railroad work when it is inconvenient to move boilers about the line. The electric wires can easily be run by ordinary workmen, and are always ready to tap at any point.

FIG. 292.



ELECTRIC ELEVATOR WITH HOIST.

"ELECTRIC TROUBLE" OF WATCHES.

There are two well known laws of magnetism that apply to watches.

The first is that any so-called magnetic metal, placed in the field of a magnet, will itself become a magnet, and will retain this magnetism in a more or less marked degree when removed from the field. Steel is an excellent example of such metals.

The second law is that similar magnetic poles repel, and dissimilar poles attract, each other. By applying these laws we arrive at a full understanding of the effect of magnetism on a pocket watch of the usual construction, and an explanation of its loss of value as a timekeeper. A watch, in the field of a magnet strong enough to stop it, will usually, when removed, at once commence running again, but its time-keeping qualities will have been ruined.

The parts affected by magnetism are the balance and springs. The balance in an ordinary watch moves five times a second; 18,000 times an hour, and 432,000 times each day. But a slight change in the forces that move it are necessary to make a difference of several minutes each day. As the balance moves back and forth the magnetism of the main-spring is pulling or pushing it. If this force was constant and always

"ELECTRIC TROUBLE" OF WATCHES.

in the same direction the watch would run uniformly. Such, however, is not the case. When the main-spring is tightly wound its magnetic poles are in a certain direction and in unwinding they are constantly changing, so that the direction of this force is also constantly changed. The effect on the balance is such as to cause the watch to run too fast sometimes and too slow other times.

Non-magnetic watches are made with these parts of a non-magnetic metal so that they are not influenced by electric machinery.

The very hard steel used for the cylinder wheel of ordinary watches is apt to become highly magnetized when brought near dynamos running; and this magnetization, combined with the earth's magnetism, always causes the watch to get slow, and often to stop altogether.

In order to annihilate this magnetization, a natural magnet or a powerful electro-magnet must be placed in a horizontal position—on a table, for instance, and the watch held horizontally about half a yard off on a level with the magnet. The watch must then be brought slowly nearer the magnet, while being turned slowly, and at the same time as regularly as possible, between the fingers, as on a vertical axis. When the poles of the magnets are reached, the turning of the watch is to be continued, while being gradually withdrawn until the starting point is reached. This simple method has often been adopted with the desired result.

ELECTRIC CLOCKS.

Electric Clocks.—Electrically controlled clocks, governed by a standard central clock, have proved a more fruitful invention. In these the standard timekeeper is constructed so as to complete a circuit periodically, once every minute or half minute. The transmitted currents set in movement the hands of a system of dials placed at distant points, by causing an electromagnet placed behind each dial to attract an armature, which, acting upon a ratchet wheel by a pawl, causes it to move forward through one tooth at each specified interval, and so carries the hands round at the same rate as those of the standard clock.

TYPES OF DYNAMOS AND MOTORS.

Scattered through this volume will be seen illustrated different types of dynamos and motors. The place of manufacture of these various machines are given as well as—in some instances—of the name of the makers.

It were vain to attempt, within the limits of this volume, to explain the differences, special advantages, and applications of each machine.

Every reputable maker of electrical machines, and there are now very many such, stands back, by warranty written or implied, of the promised performance of his product, so each manufacturer is alert to improve by additions or changes his special designed machine.

ACCIDENTS AND EMERGENCIES.

The introduction of electricity as an industrial and useful agent has been attended with many distressing accidents, causing great suffering and frequently loss of life.

Three instances are given of the latter to emphasize the necessity of constant care and skill in those in attendance on electrical apparatus:

"Charles Gruive, 30 years old, night electrical engineer of the East River Electric Light Company, was shocked to death at 10:30 o'clock last night in the company's plant at 425 East 24th street, New York.

He had been standing for several minutes near one of the great dynamos on the second floor, when he was heard by a workman standing close by to utter a slight cry. He fell to the floor, and the workman, running immediately to him, found him unconscious. Physicians from Bellevue Hospital tried a number of methods of resuscitation—artificial respiration, hypodermic injections, etc.—but to no avail.

An examination of the body by Dr. Hoyt showed only two burus across the hand, so slight that they wonld not have been noticed in any other case. The face of the dead man showed no sign of pain, nor was any part of the body distorted. One of the workmen in the building said that the number of volts from the dynamos on that floor was something over 1,200.

Gruive lived in Hoboken with a wife and three children, and had been employed for a long time by the company, being considered a careful and clever man. He went on duty at 6 o'clock last night in perfect health and in good spirits."

"Louis Wentz, a press boy in the *Times* office, Leavenworth, Kansas, was instantly killed this morning by taking hold of a poorly insulated electric-light wire. The pressroom lights had gone out, and in attempting to regulate them, holding the wire in his left hand, his right hand

ACCIDENTS AND EMERGENCIES.

touched a screw coupling a circuit. The pressman tried to pull the boy away from the wire and received a shock which knocked him senseless for a time."

"George Sullivan, a plumber, who was engaged in making repairs at the Birmingham Company's power house, Pittsburgh, Penn., was killed by a live wire at noon to-day. With a fellow workman he mounted a ladder to make a connection near the ceiling. His companion held the pipe, and Sullivan began to drive a nail into the wall to hold it. In striking at the nail he missed it and struck a live wire. An awful flash resulted. Sullivan fell backward, striking another live wire with the back of his neck. He was thrown into the air, and then fell to the floor, dead."

Happily, while these accidents are becoming less frequent, none the less it is important to both know and observe the rules for safety so constantly repeated.

Reference is again particularly and emphatically made to the "cautions" printed under the heading of Electric Railways, pages 441 and 447 inclusive, as well as to what follows.

The Electric Shock.—Currents of electricity passed through the limbs affect the nerves with certain painful sensations, and cause the muscles to undergo involuntary contractions.

NOTE.—"A rat in the City Electrical Light Works of Baltimore played havoc. He stepped from one brass terminal to another, with his front feet on one pole and his hind feet on the other, thus being subjected to 2,700 volts. In an instant there was a flash, a heavy ironstone piece of insulation was smashed, the net-work of wires blazed up, setting fire to the wooden frames of the switchboard, and hundreds of houses were plunged in darkness. The hair of the rat was completely burned off and the body became rigid as if suddenly frozen in the act of stepping across the terminals. Although the hair was burned off and even the skull bone protrnded, the body being instantly carbonized and rendered rigid, its attitude, when discovered, was life-like."

"Some time ago a tame leopard escaped from its keepers at Bridgeport, Conn., and climbed an electric light pole and began monkeying with the wires. Not being posted in electric science the leopard got knocked out. The skin was presented to a museum."

ACCIDENTS AND EMERGENCIES.

The effect experienced by the discharge of electricity with high potential difference through the animal system is that of a sharp and painful *shock;* pain and violent muscular contraction accompany it. The voltage is the main element of shock, amperage has also some direct influence.

Of currents, an alternating current is reputed worse than a direct current, in producing a dangerous shock.

Electric Prostration.—The voltaic arc (arc light) is the source of the most intense heat and brightest light producible by man; too great exposure to its rays in its more powerful forms causes symptoms resembling those of sunstroke. The skin is sometimes affected to such a degree as to come off after a few days. The throat, forehead and face suffer pains, and the eyes are irritated. These effects only follow exposure to very intense sources of light, or for very long times.

The condition of the body after death by electric shock corresponds exactly with that found after death by asphyxia. The electric shock paralyzes or destroys the nerve centre which controls the respiratory movements; the passage of venous blood into the arterial system causes contraction of the arterioles, and finally stoppage of the heart exactly as in death by drowning or suffocation. There is, therefore always hope of resuscitation, except when the respiratory nerve centre has been destroyed. M. D'Arsonval mentions a case in which a workman was stunned by being subjected, for a short time, to a pressure of 4,500 volts. About a quarter of an hour after the accident, assistance arrived, and artificial

respiration was practised. In two hours the man was able to speak, and finally was completely restored.

The D'Arsonville Method of Resuscitation.

The proof of the efficacy of this method is now so complete that no one following electrical pursuits in which there is danger from electric shocks, is justified in neglecting to make himself familiar with it.

First, it must be appreciated that accidental shocks seldom result in absolute death unless the victim is left unaided for too long a time, or efforts at resuscitation are suspended too early.

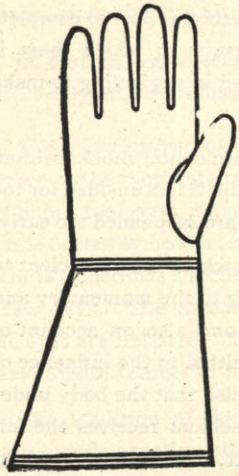
In the majority of instances the shock is only sufficient to suspend animation temporarily, owing to the momentary and imperfect contact of the conductors, and also on account of the indifferent parts of the body submitted to the influence of the current. It must be appreciated also that the body under the conditions of accidental shocks seldom receives the full force of the current in the circuit, but only a shunt current, which may represent a very insignificant part of it.

When an accident of this nature occurs, the following rules should be promptly adopted and executed with due care and deliberation:

1.—Remove the body at once from the circuit by breaking contact with the conductors. This may be accomplished by using a dry stick of wood, which is a non-conductor, to roll the body over to one side, or to brush aside a wire, if that is conveying the current. When a stick is not at hand, any dry

piece of clothing may be utilized to protect the hand in seizing the body of the victim, unless rubber gloves are convenient. If the body is in contact with the earth, the coat-tails of the victim, or any loose or detached piece of clothing, may be seized with impunity to draw it away from the conductor. When this has been accomplished, observe Rule 2.

FIG. 293.



LONG ACID GLOVE.

FIG. 294.

SHORT GLOVE.

2.—Turn the body upon the back, loosen the collar and clothing about the neck, roll up a coat and place it under the shoulders, so as to throw the head back, and then make efforts to establish artificial respiration (in other words, make him breathe), just as would be done in case of drowning. To accomplish this, kneel at the subject's head, facing him, and seizing both arms draw them forcibly to their full length over the head, so as to bring them almost together above it, and

NOTE.—Linemen's rubber gloves (see illustration) are designed to prevent the frequent and often fatal accidents occurring to linemen from shock while handling electric light wires or other wires in contact with the same, and also the dangers of line work from lightning in stormy weather. The gloves are also useful in handling the strong acids of batteries, being impervious to the same.

hold them there for two or three seconds only. (This is to expand the chest and favor the entrance of air into the lungs). Then carry the arms down to the sides and front of the chest, firmly compressing the chest walls, and expel the air from the lungs. Repeat this manœuvre at least sixteen times per minute. These efforts should be continued unremittingly for at least an hour, or until natural respiration is established.

3.—At the same time that this is being done, some one should grasp the tongue of the subject with a handkerchief or piece of cloth to prevent it slipping, and draw it forcibly out when the arms are extended above the head, and allow it to recede when the chest is compressed. This manœuvre should likewise be repeated at least sixteen times per minute. This serves the double purpose of freeing the throat so as to permit air to enter the lungs, and also, by exciting a reflex irritation from forcible contact of the under part of the tongue against the lower teeth, frequently stimulates an involuntary effort at respiration. If the teeth are clenched and the mouth cannot be opened readily to secure the tongue, force it open with a stick, a piece of wood, or the handle of a pocket knife.

While this is being done, a physician should be summoned.

Electric Protector.—This is a protective device for guarding the human body from destructive or injurious electric shocks. In one system, Delany's, the wrists and ankles are encircled by conducting bands, which, by wires running along the arms, back and legs, are connected. A discharge, it is assumed, received by the hands will thus be short circuited around the body and its vital organs.

CAUTION.

Quotation.—"Of nearly all accidents arising from contact with electric wires and electric machines it may be said it is more the want of care than the want of knowledge." The Fig. 295 is a reminder of the necessity for constant care and watchfulness upon the part of all who have aught to do with electricity.

FIG. 295.

DANGER SIGNAL.

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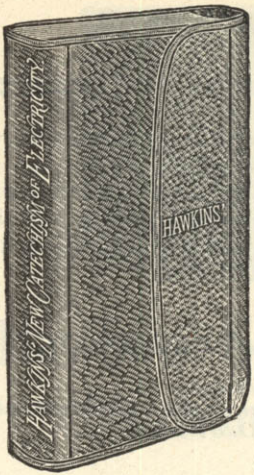

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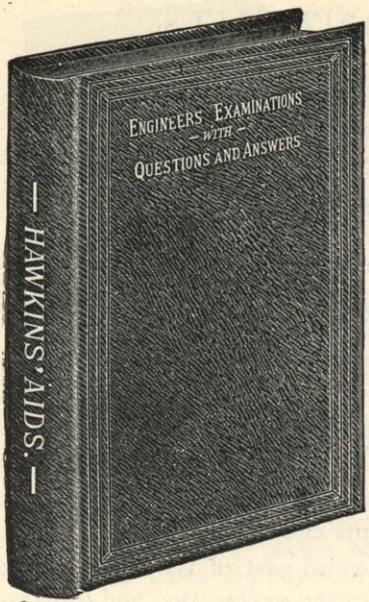

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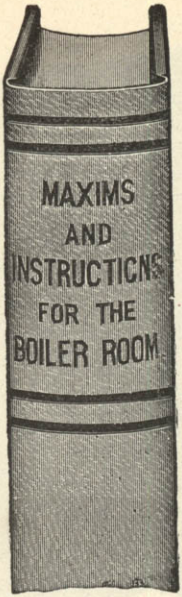

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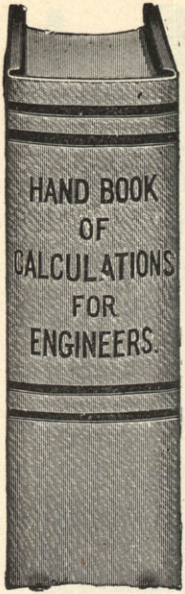

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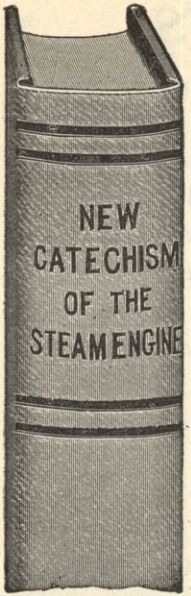

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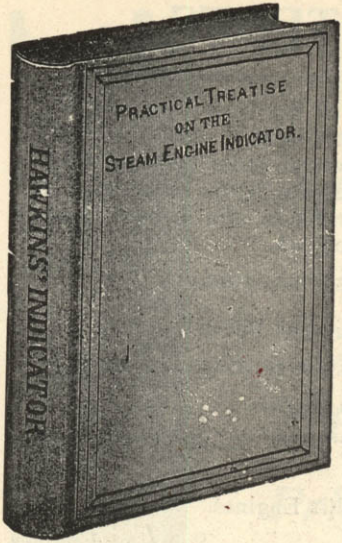

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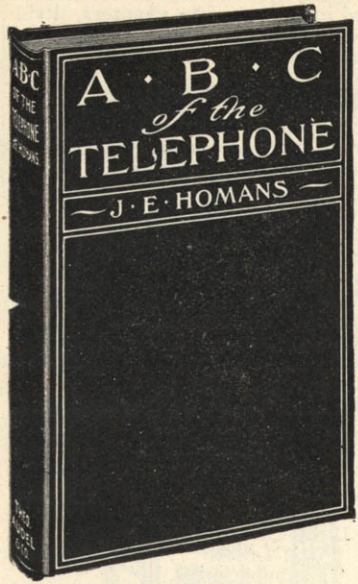

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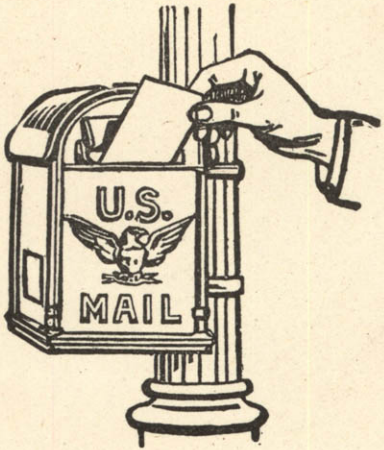

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